MISCELLANEOUS PAPER NO. 4-859

FREQUENCY SPECTRUM METHOD FOR ANALYZING GROUND-MOTION DATA PRODUCED BY SINGLE AND MULTIPLE VIBRATORY SOURCES

by

R. F. Ballard, Jr.
R. E. Leach

December 1966

Sponsored by

Office, Chief of Research and Development
through
U. S. Army Materiel Command

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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Foreword

This investigation was sponsored through the U. S. Army Materiel Command, by the Office, Chief of Research and Development under Department of the Army Project 1L013001A91A, "In-House Laboratory Independent Research Program," (WES Item 0). The study was conducted in connection with ground motion studies of wave propagation resulting from controlled sinusoidal and random-induced motion. The field investigations were performed from 7 through 22 March 1966.

Engineers of the Waterways Experiment Station (WES) who were actively engaged in the field investigations, analysis, and report phases of this study were Messrs. R. W. Cunny, Z. B. Fry, R. F. Ballard, Jr., and R. E. Leach of the Soils Division and Messrs. H. C. Greer III, E. T. Estes, and A. S. Lessem of the Instrumentation Branch. The work was performed under the general supervision of Messrs. W. J. Turnbull and A. A. Maxwell, Chief and Assistant Chief, respectively, of the Soils Division. This report was prepared by Messrs. Ballard and Leach.

Col. John R. Oswalt, Jr., CE, was Director of the WES during the conduct of the investigation and publication of this report. Mr. J. B. Tiffany was Technical Director.

Contents

Summary

Tests were conducted at the Waterways Experiment Station (WES) to investigate controlled single and multiple source vibrations induced in an earth media with the primary objective of evaluating the benefits afforded by two data reduction techniques in identifying the frequency and amplitude composition of the ground motion at selected locations. Single signals of known frequency and force level were induced to the ground surface by three types of vibrators mounted on a 10-ft-diameter concrete base. The resultant particle velocities were measured triaxially at each of four locations: on the base and 15, 35, and 90 ft from the base. After the single source tests, the vibrators were operated simultaneously as a multiple signal source input. Data were again recorded at the same locations. Special tests were then performed with two electrodynamic vibrators on the ground surface operating both singly and simultaneously.

Ground motions associated with each type of test were recorded both on oscillograph and magnetic tape recorders. Data were reduced manually and directly compared to an automatic frequency spectrum analysis of the data from the vertically oriented transducers. Results indicate conclusively that highly accurate correlations can be made. The data will be subjected to further study in regard to amplitude attenuation and wave shape at distances from the source. Measurements for future ground motion studies conducted at the WES will be obtained in a manner such that an automatic frequency spectrum analysis can be conducted. The test results also showed that correlations between known input signals from single sources can be directly compared with multiple signals at corresponding frequencies and force levels.

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FREQUENCY SPECTRUM METHOD FOR ANALYZING GROUND-MOTION DATA PRODUCED BY SINGLE AND MULTIPLE VIBRATORY SOURCES

Background, Objectives, and Scope of Study

1. When ground motion resulting from space vehicle launchings and other vibratory loadings is monitored, the resulting data are highly complex and random, and thus extremely difficult to analyze and correlate. An attempt was made to reduce such data with a frequency spectrum analyzer, and the preliminary analysis was reported at the Dynamic Foundation Studies Consultants Conference held at the U. S. Army Engineer District, Canaveral, 3-5 July 1965. In the preliminary study, attention was directed primarily to frequency and amplitude of motion with respect to time and distance from the exciter. The consultants recommended that a more basic and simpler approach be adopted with the aim of achieving a better understanding of random waves propagated through soil media.

2. The tests reported herein were conducted to investigate induced sinusoidal and random motion and the resulting signals received at given points on or beneath the ground surface. The specific purposes of the study were to determine (a) the ground motion velocities at given locations produced by single and multiple, controlled wave shapes induced by vibratory sources; (b) the most reliable and functional method of data reduction, interpretation, and presentation; and (c) whether it appears possible to correlate these data with those obtained from space-vehicle launches and other vibratory loadings of structures.

3. The study was accomplished by in situ dynamic tests performed with available equipment at a site on the Waterways Experiment Station (WES) reservation. Data were subjected to both manual and automatic reduction techniques for comparative purposes.

Scope of This Report

4. This report describes the test site, equipment used, test procedures and results, and the data reduction methods used. The manually

reduced data are tabulated herein. One set of the data (vertical velocities) were analyzed by the frequency spectrum method and the results plotted, primarily to show the degree of correlation between the two data reduction methods. All of the data obtained in the tests will be subjected to further study in regard to amplitude attenuation and wave shape at distances from the vibratory source if future studies indicate that this information is desirable.

The Investigation

Location and description of test site

5. The initial consideration in selection of the test site was uniformity of subsurface conditions. The site selected is a level area where previous large-scale vibratory tests have been conducted. The soil at the site is a uniform silty clay (loess) to a depth of approximately 20 ft; from 20 to 100 ft, a bluish clay is predominant. Limestone is encountered at greater depths.

Equipment

6. Vibrators. The exciting equipment used to produce steady-state motion for this study consisted of four separate vibrators, as follows.

a. A low-frequency, motor-driven vibration generator capable of developing sinusoidal forces and moments in several directions was used to produce vertical motion within its frequency range of 0 to 30 cps. This vibrator, procured from the U. S. Navy David Taylor Model Basin (DTMB), consists of two parallel-mounted, d-c motors connected by idler gears with an eccentric mass on each end of the shafts. The masses are counterrotating and their eccentricity can be varied from 0.1 to 4 in. An eccentric setting of 0.1 in. was used throughout the test series. This vibrator was mounted on a 10-ft-diameter, circular, reinforced concrete base weighing 25,370 lb.

b. An intermediate range, hydraulic-powered, counterrotating mass vibrator was used to produce vertical sinusoidal motion within the frequency range of 0 to 50 cps. This vibrator was designed and constructed at the WES. Various force levels are achieved by attaching sets of masses on a fixed eccentricity of 4 in. A total eccentric weight of 5 lb was used throughout the test series. The hydraulic vibrator was

mounted on a 2-in.-thick, rigid steel plate which in turn was bolted atop the DTMB vibrator.

c. Two electromagnetic vibrators with a rated force of 50 lb each were used to impart vertical sinusoidal motion within the frequency range of 30 to 100 cps. To achieve a sufficient force level, the vibrators were paralleled to the output of a 150-watt power amplifier, and therefore functioned as a single vibrator with a force output of 100 lb for the initial series of tests. The vibrators were epoxied to the concrete base, one on each side of the DTMB vibrator and equidistant from the set of transducers mounted on the pad, as shown in photographs 1 and 2.

7. Transducers. The selection of transducers to measure the movement of the concrete base and ground surface when subjected to a vibratory force was given careful consideration. Moving coil velocity-type pickups were chosen for their sensitivity, uniform phase relations, and frequency response. Twelve transducers, each with a natural frequency of 2.50 cps and a sensitivity of 96.3 mv/in./sec, were used throughout the test program. The pickups were mounted triaxially on four aluminum mounts. Thus, four groups of three pickups each were positioned to monitor movements in the vertical, radial, and transverse directions. One group was epoxied to the concrete base, and the remaining three groups were located 15, 35, and 90 ft from the base. Four 5-in. spikes were attached to each of the far-field groups and were driven into the ground to ensure intimate contact with the ground surface. To minimize wind and extraneous noises, the pickups were then buried flush with the ground surface.

8. Recorders. An 18-channel, direct-readout oscillograph was used as one method of recording data; however, the prime effort was concentrated on a 14-channel, magnetic tape system. The data-gathering chain originated with the 12 transducers, was amplified by 12 channels of d-c amplifiers, and was terminated simultaneously in each recorder. Since the tape was scheduled for data reduction on a frequency spectrum analyzer, each test run was recorded for one full minute to achieve an acceptable level of confidence in the data to be analyzed.

9. Frequency spectrum analyzer. The prime purpose for recording the data on magnetic tape in addition to the conventional oscillograph was to utilize the advantages of a rather sophisticated, modular, frequency

spectrum analyzer system available at the WES. This analyzer, constructed by Gulton Industries, Inc., is the Ortholog Model OR-WA/1. The Ortholog wave analyzer uses heterodyne or mixing techniques to sweep the analyzing filter through different frequencies of the signal being analyzed. The basic difference from conventional analog wave analyzers is that, instead of a high frequency band-pass filter, a low-pass filter with "zero center frequency" is used to analyze difference frequency components from the modulator. This new technique introduces a principle whereby the data are analyzed by ultrasharp cutoff low-pass filters. Use of these active, highly selective filters results in an analyzer with excellent selectivity and dynamic range characteristics. The basic system consists of a highly stable precision sine wave local oscillator variable over the desired analysis frequency range. This oscillator is voltage-controlled, and servo-stabilized without the introduction of electromechanical components. In manual operation, the voltage is supplied by a potentiometer. In the automatic-sweep mode, the voltage is supplied by an electronic sweep generator. The output of the oscillator mixes with the incoming data signal in a pure modulator (i.e. one that modulates by pure multiplication using the "quarter-squares" techniques). Difference frequencies resulting at the modulator output are analyzed by a low-pass IF (intermediate frequency) filter, which is available in a wide range of analyzing bandwidths. The output of the analyzing low-pass filter can be fed, at the operator's option, to either a linear or a square law detector. The linear and square law detectors can operate into RC (resistance capacitance) smoothing networks which have time constants that can be varied for compatibility with data sweep rate and analyzing-filter bandwidth. It should be noted that the phase shift characteristics throughout the Ortholog spectrum analyzers can be matched to within 1 deg. This phase shift matching includes the filters, a feat impossible to accomplish when highly tuned, quartz crystal lattice filters or other high IF filters are used. It is this characteristic of the filters that makes the Ortholog spectrum analyzer so useful for cross-power spectral density analysis (vector transfer function computation), in which phase must be carefully preserved through the several channels of the system.

Test procedures

10. The four vibrators were affixed to the 10-ft-diameter, circular concrete base as shown in photographs 1 and 2. A common base was chosen to minimize possible variables and interaction that might have been encountered if the vibrators had been seated individually on the soil. This arrangement was also thought to basically simulate a launch pad or any other type of vibrating structure which might induce substantial ground motion.

11. The velocity-type transducers were located triaxially at each of the four locations mentioned earlier: on the base and flush with the ground surface at distances 15, 35, and 90 ft from the edge of the pad.

12. Initially, each vibrator was operated individually (except for the small electromagnetic vibrators which functioned as a single unit) at specific frequencies and force levels. Data were recorded independently and simultaneously on magnetic tape and an oscillograph. Subsequently, the vibrators were operated simultaneously at different frequencies and data were again recorded.

13. Upon completion of multiple vibrator tests, a group of special tests in which the small electromagnetic vibrators were connected to separate power amplifiers and repositioned on the ground surface was conducted. The first group of transducers was relocated at a point 3 ft from the vibrators while the positions of the remaining groups remained unchanged. This test setup is shown in photograph 3. The two electromagnetic vibrators were operated individually at specific frequencies, then simultaneously at different frequencies. Data were recorded in the same manner as in the initial tests.

14. The individual vibrator tests were performed to establish a "zero reference" in regard to wave shape and amplitude for individual frequencies measured at each pickup location. The multiple vibrator tests were then conducted at chosen combinations of frequencies which could be directly related to the individual "zero reference" test runs.

Tests and Results

Single vibrator tests

15. DTMB vibrator. The first sequence of tests was conducted

utilizing only the DTMB vibrator to produce sinusoidal motion in the vertical mode. The vibrator was operated at specific frequencies from 7 to 25 cps at a constant eccentric setting of 0.1 in., producing force levels from 715 to 9125 lb (table 1). The data recorded on the oscillograph and reduced in terms of peak-to-peak particle velocity by manual scaling techniques are given in table 1. Plate 1 shows the relation between vibrator frequency and peak-to-peak vertical* velocity measured on and 15 ft from the base.

16. Hydraulic vibrator. The hydraulic vibrator was the next to be tested. Selected individual frequencies from 7 to 50 cps produced force levels from 100 to 5090 lb with a total eccentric weight of 5 lb (table 1). Manually reduced velocities are given in table 1, and a plot of frequency versus particle velocity on and 15 ft from the base is shown in plate 2.

17. Electromagnetic vibrators. As previously stated, the two electromagnetic vibrators were operated in tandem as a single unit. They were operated at a constant force level of about 100 lb for the selected frequencies from 30 to 100 cps (table 1). Data obtained on the oscillograph were of extremely low magnitude and virtually unmeasurable in some cases. Reduced data, given in table 1, were not sufficient for the development of a graphic relation.

Multiple vibrator tests

18. Common base. The multiple vibrator tests conducted on the common base were sequenced to correlate with the previous individual vibrator runs. Selected frequencies from the individual tests conducted for each vibrator were combined. The DTMB, hydraulic, and electromagnetic vibrators were operated at frequencies of from 7, 16, and 50 cps up to 25, 50, and 100 cps, respectively. The combination of frequencies, the forces produced, and the peak-to-peak particle velocities measured are given in table 2.

19. Special tests. In the series of special tests conducted with the electromagnetic vibrators on the ground near the concrete base, the vibrators were operated separately, one at 30 and the other at 40 cps, then together

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* Vertical, radial, and transverse velocities were recorded by the transducers and are given in tables 1 and 2. However, only vertical velocities were reduced by the frequency spectrum analyzer and analyzed graphically herein.

at the same frequency used before. Data for these tests are also shown in table 2.

Frequency spectrum analysis

20. The prime objective in the data analysis procedure was to determine the reliability and effectiveness of automatic data analysis with the frequency spectrum analyzer. The data from the vertically oriented transducers were used for this purpose.

21. Because the field records were ground responses to fixed-frequency, fixed-amplitude excitations, it was anticipated that the amplitude spectra obtained would be essentially line spectra. These are characteristic of nonrandom complex signals. The magnetic-tape field records were reproduced in the data reduction laboratory and tape loops made. These were played back into the wave analyzer under the following real time conditions: (a) bandwidth, 2.5 cps; (b) scan interval, 5 to 200 cps; (c) scan time, 2400 sec; (d) detector time constant, 2 sec. In order to achieve a satisfactory signal-to-noise ratio, the transducer signals were recorded with gains approximately in inverse proportion to the signal strengths. The wave analyzer gain was adjusted to compensate for this preconditioning, thereby presenting true peak-to-peak particle velocities.

22. Certain test results are grouped in this report to facilitate direct comparison of the results obtained with the multiple-controlled vibratory sources compared to the "zero reference" runs which consisted of each vibratory source operating singly. For example, plate 3 shows a portion of the original wave shape and the frequency spectrum analysis for particle velocities measured on the concrete base with three vibrators running simultaneously at frequencies of 7, 16, and 50 cps. Plate 4 then depicts concurrent measurements for the pickup location 15 ft from the base. Plates 5 and 6 show the "zero reference" frequency of 7 cps generated by the DTMB vibrator alone for measurements on and 15 ft from the base, respectively. Plates 7 and 8 present the reference frequencies of the hydraulic and plates 9 and 10 those for the electromagnetic vibrators in the same sequence. In certain selected cases (selected because of adequate amplitude and good signal quality) the data from the far-field locations (35 and 90 ft) are presented in addition to those obtained on and 15 ft from the base so that

amplitude attenuation can be compared. Plates 11-14 are examples of data obtained at the four pickup locations for the multiple signals of 16, 27, and 50 cps. The following tabulation will aid in examining the data presented herein.

Vibrator	Frequency cps	Pickup Location	Plate
All	7, 16, 50	On base	3
All	7, 16, 50	15 ft from base	4
DTMB	7	On base	5
DTMB	7	15 ft from base	6
Hydraulic	16	On base	7
Hydraulic	16	15 ft from base	8
Electromagnetic	50	On base	9
Electromagnetic	50	15 ft from base	10
All	16, 27, 50	On base	11
All	16, 27, 50	15 ft from base	12
All	16, 27, 50	35 ft from base	13
All	16, 27, 50	90 ft from base	14
DTMB	16	On base	15
DTMB	16	15 ft from base	16
Hydraulic	27	On base	17
Hydraulic	27	15 ft from base	18
Electromagnetic	50	On base	9
Electromagnetic	50	15 ft from base	10
All	10, 20, 30	On base	19
All	10, 20, 30	15 ft from base	20
DTMB	10	On base	21
DTMB	10	15 ft from base	22
Hydraulic	20	On base	23
Hydraulic	20	15 ft from base	24
Electromagnetic	30	On base	25
Electromagnetic	30	15 ft from base	26
All	20, 40, 80	On base	27

(Continued)

Vibrator	Frequency cps	Pickup Location	Plate
All	20, 40, 80	15 ft from base	28
DTMB	20	On base	29
DTMB	20	15 ft from base	30
Hydraulic	40	On base	31
Hydraulic	40	15 ft from base	32
Electromagnetic	80	On base	33
Electromagnetic	80	15 ft from base	34
All	25, 50, 100	On base	35
All	25, 50, 100	15 ft from base	36
All	25, 50, 100	35 ft from base	37
All	25, 50, 100	90 ft from base	38
DTMB	25	On base	39
DTMB	25	15 ft from base	40
Hydraulic	50	On base	41
Hydraulic	50	15 ft from base	42
Electromagnetic	100	On base	43
Electromagnetic	100	15 ft from base	44
Electromagnetic	30, 40	3 ft from vibrators	45
Electromagnetic	30, 40	13 ft from vibrators	46
Electromagnetic	30, 40	33 ft from vibrators	47
Electromagnetic	30, 40	88 ft from vibrators	48
Electromagnetic	30	3 ft from vibrator	49
Electromagnetic	30	13 ft from vibrator	50
Electromagnetic	40	3 ft from vibrator	51
Electromagnetic	40	13 ft from vibrator	52

It should be stated that a slight variation (usually less than 1 cps) of frequency at which maximum amplitudes should have occurred sometimes appears on the frequency spectrum analysis plots. This discrepancy is probably due to some minor problems which occurred with the X-Y recorder in its horizontal tracking mode. These difficulties are presently being resolved.

23. Maximum amplitudes at the vibrator frequencies resulting from the multiple sources correlate extremely well with the individual runs at

the same respective frequencies. A corresponding comparison of the manually reduced data presented in tables 1 and 2 with the frequency spectrum analysis data plotted in plates 3-52 also reveals excellent correlation, and the particle velocities scaled from the oscillograph records for the multiple signal sources correspond directly to the predominant amplitude of the frequency exhibited on the associated frequency spectrum analysis plot. Example of amplitude comparisons between multiple source and individual "zero reference" source data obtained by manual reduction and spectrum analysis are shown in the following tabulation, which was derived from plates 19-26.

	Multiple Signal Source				"Zero Reference" Source			
	Spectrum Analysis		Manual Reduction		Spectrum Analysis		Manual Reduction	
Frequency cps	Ref Plate	Amplitude	Ref Table	Amplitude	Ref Plate	Amplitude	Ref Table	Amplitude
				On the Base				
10	19	0.125	2	--	21	0.135	1	0.143
20		0.160		0.200	23	0.145		0.129
30		0.045		--	25	0.027		0.023
				15 ft from the Base				
10	20	0.015	2	--	22	0.018	1	0.018
20		0.028		0.030	24	0.028		0.026
30		0.009		--	26	0.012		0.014

In the case of the manual data reduction of the multiple signal data, the resultant wave shape was, of course, nonsinusoidal, so only a maximum particle velocity which was (in every case) indicative of the predominant frequency could be accurately determined.

Conclusions

24. The test results showed that correlations between known input signals from single sources can be directly compared with multiple signals at corresponding frequencies and force levels.

25. Comparisons of data reduced by the two methods--by conventional

manual scaling from oscillograph traces and by automatic frequency spectrum analysis--resulted in excellent correlations and allowed identification of the frequency and amplitude composition of the ground motion data. Thus, it is concluded that the frequency spectrum analysis method can be utilized in future ground motion studies as an accurate data presentation technique.

26. Measurements for future ground motion studies conducted by the WES should be obtained in a manner such that an automatic frequency spectrum analysis can be conducted.

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Table 1

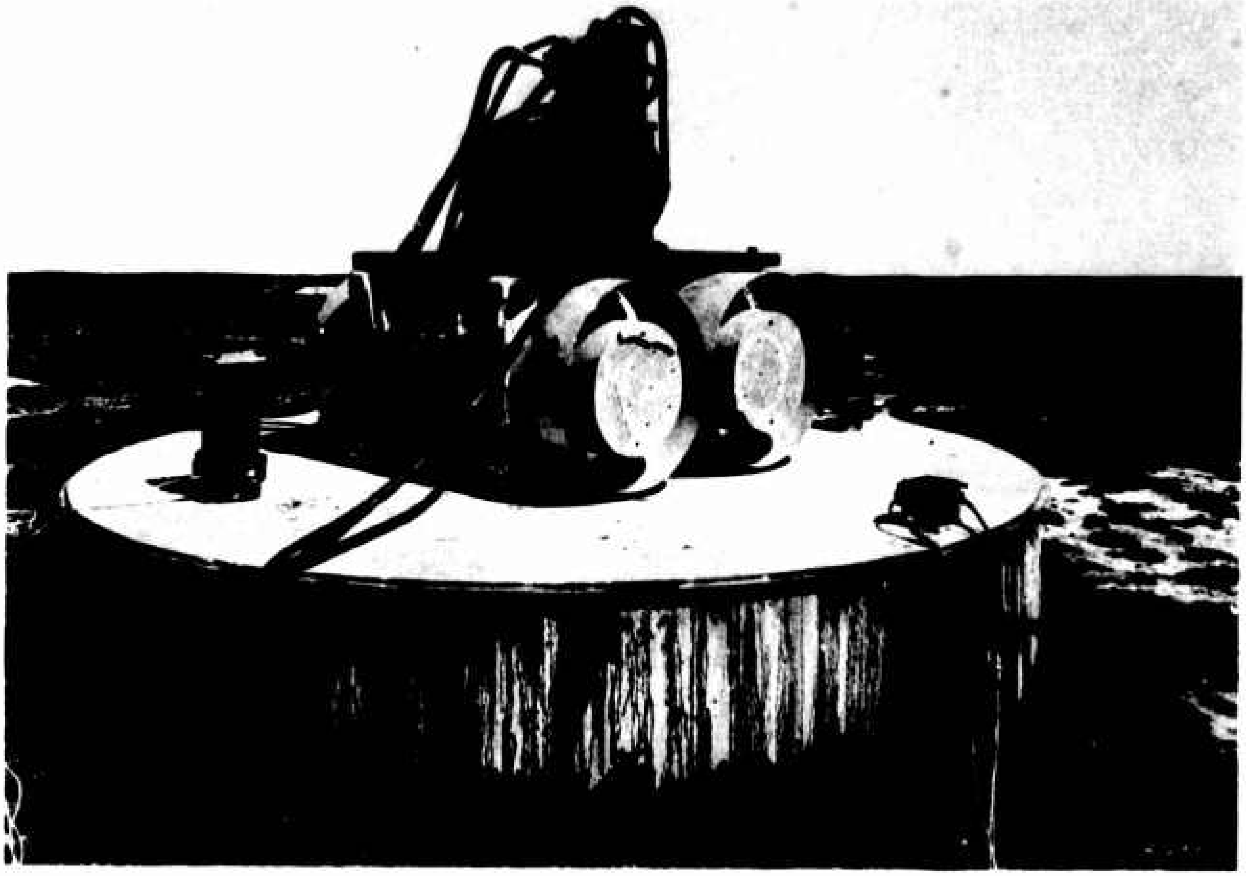
Results of Individual Vibrator Tests

Frequency cps	Force lb	On Base Vertical	On Base Radial	On Base Transverse	15 ft from Base Vertical	15 ft from Base Radial	15 ft from Base Transverse	35 ft from Base Vertical	35 ft from Base Radial	35 ft from Base Transverse	90 ft from Base Vertical	90 ft from Base Radial	90 ft from Base Transverse
		Peak-to-Peak Velocity, 10^{-2} ips, for Indicated Velocity Pickup Location and Orientation											
					[illegible] Vibrator, 0.1-in. Eccentricity								
[illegible]	715	[illegible]	--	--	[illegible]	--	--	--	--	--	--	--	--
[illegible]	1180	9.83	0.331	--	1.15	--	--	--	0.714	--	--	--	--
[illegible]	1460	14.32	4.24	1.8	1.78	0.57	0.793	0.682	1.03	--	--	0.473	0.367
[illegible]	2105	27.15	4.73	3.85	3.0	0.81	[illegible]	1.7	2.67	--	0.391	0.473	0.367
14	2800	45.0	8.37	4.64	5.66	0.80	0.84	3.00	5.17	1.17	0.487	0.85	0.614
[illegible]	3740	[illegible]	11.5	[illegible]	9.43	4.84	[illegible]	[illegible]	9.23	[illegible]	0.876	0.658	0.614
[illegible]	4725	91.7	13.3	[illegible]	15.19	9.43	1.45	5.46	11.8	1.82	0.977	4.33	1.6
[illegible]	5840	120.0	13.2	6.0	16.35	10.7	1.72	5.54	11.8	2.4	0.692	6.23	1.17
[illegible]	7070	135.[illegible]	13.3	6.88	18.88	14.1	1.8	7.15	11.8	3.11	1.105	6.76	2.71
[illegible]	8405	[illegible]	12.8	5.15	22.0	15.2	1.76	8.28	12.8	2.67	4.78	6.14	3.42
[illegible]	9125	147.0	15.3	9.43	25.45	14.1	2.55	10.25	12.35	2.13	5.37	5.57	3.05
					Hydraulic Vibrator, 5-lb wt								
[illegible]	100	0.39	--	0.257	--	--	--	--	--	--	--	--	--
[illegible]	165	0.39	--	0.257	--	--	--	--	--	--	--	--	--
11	247	1.0	--	--	0.628	--	--	--	--	--	--	--	--
13	345	[illegible]	1.26	--	0.94	--	--	0.682	0.514	--	0.585	--	--
[illegible]	450	5.04	--	--	1.15	0.484	--	1.07	1.44	--	0.781	--	--
[illegible]	533	7.75	--	[illegible]	1.47	1.53	--	1.27	1.75	--	0.876	0.19	--
[illegible]	[illegible]	[illegible]	--	0.934	2.1	1.7	--	1.46	2.05	--	0.88	0.755	--
[illegible]	[illegible]	12.0	[illegible]	[illegible]	2.62	1.04	0.686	1.36	2.06	0.747	0.683	1.5	--
[illegible]	[illegible]	13.0	[illegible]	1.35	1.73	2.34	0.306	1.46	2.26	1.07	0.585	1.7	--
[illegible]	1175	15.5	1.73	1.47	2.83	2.75	0.764	1.75	2.26	0.854	0.878	1.6	--
[illegible]	1380	15.5	[illegible]	1.35	3.73	2.53	1.3	1.85	2.26	0.854	0.878	1.6	--
[illegible]	1480	[illegible]	[illegible]	[illegible]	3.88	3.11	0.916	2.05	2.47	0.854	0.781	1.6	--
[illegible]	[illegible]	27.7	13.6	9.0	4.04	2.31	1.3	2.05	0.719	[illegible]	0.487	0.85	--
[illegible]	5000	112.5	46.3	13.4	12.55	6.33	2.14	2.83	2.47	0.854	0.683	0.566	--
					Electromagnetic Vibrators								
[illegible]	100	2.33	1.1	2.57	1.36	1.53	1.15	0.877	0.823	0.747	0.391	0.658	--
[illegible]	100	1.625	--	--	0.73	--	--	0.585	0.205	0.213	0.195	0.188	--
[illegible]	100	1.39	--	--	0.21	--	--	0.486	--	--	0.486	--	--
[illegible]	100	--	--	--	--	--	--	--	--	--	--	--	--
[illegible]	100	--	--	--	--	--	--	--	--	--	--	--	--
[illegible]	100	--	--	--	--	--	--	--	--	--	--	--	--
[illegible]	100	--	--	--	--	--	--	--	--	--	--	--	--
[illegible]	100	--	--	--	--	--	--	--	--	--	--	--	--

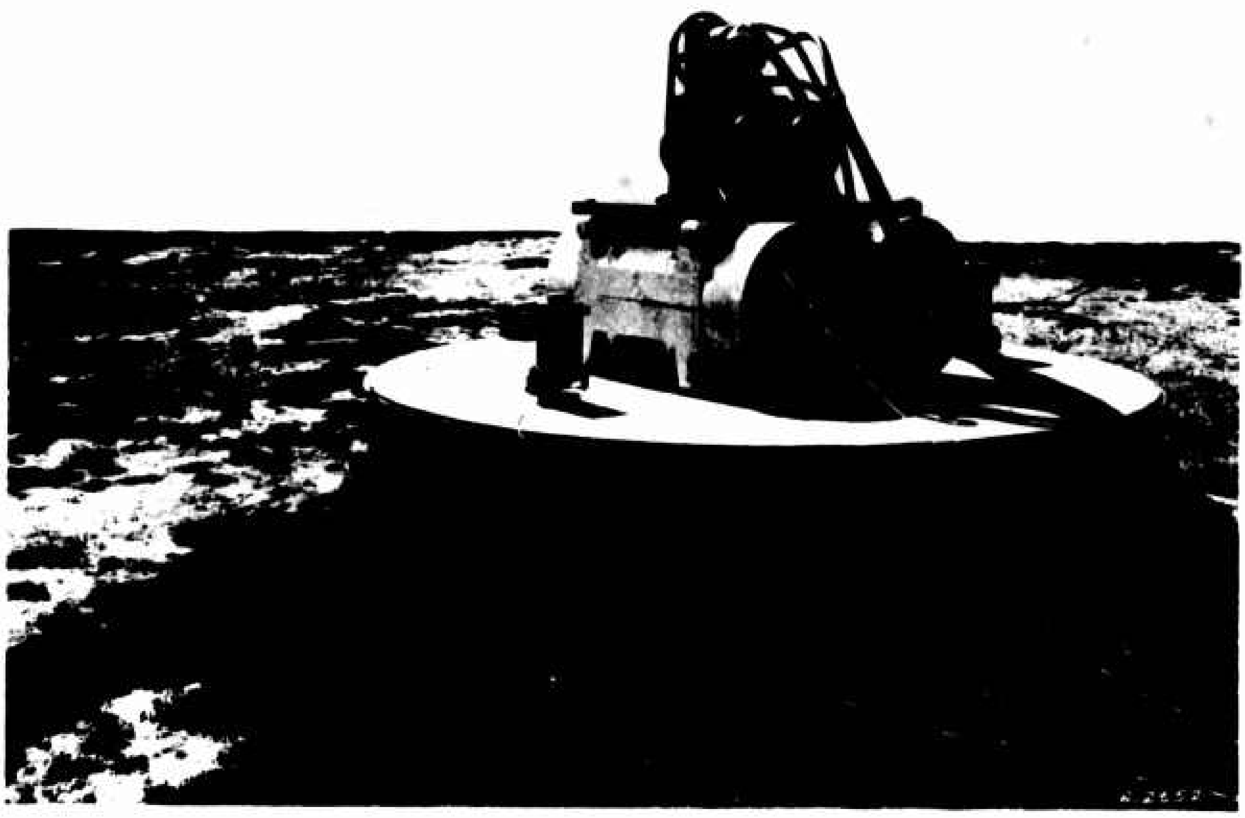
Table 2

Results of Multiple Vibrator and Special Electromagnetic Vibrator Tests

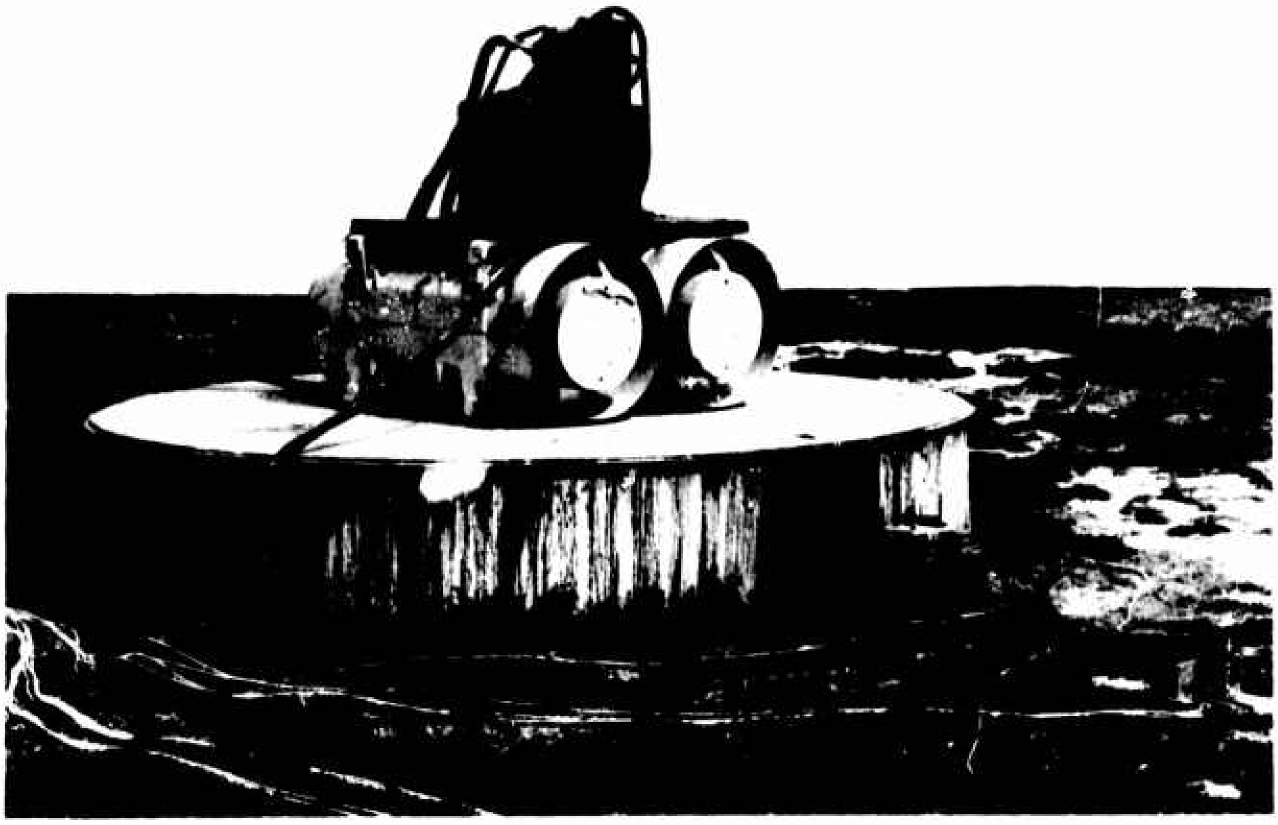
Prime Frequency cps	DTMB Vibrator 0.1-in. Eccentricity: Frequency cps	DTMB Vibrator: Force lb	Hydraulic Vibrator 5-lb wt: Frequency cps	Hydraulic Vibrator: Force lb	Electromagnetic Vibrators: Frequency cps	Electromagnetic Vibrators: Force lb	Peak-to-Peak Velocity, 10^{-2} ips, for Indicated Velocity Pickup Location and Orientation: On Base Vertical	On Base Radial	On Base Transverse	15 ft from Base Vertical	15 ft from Base Radial	15 ft from Base Transverse	35 ft from Base Vertical	35 ft from Base Radial	35 ft from Base Transverse	90 ft from Base Vertical	90 ft from Base Radial	90 ft from Base Transverse
7, 16, 50	7	715	16	523	50	100	9.28	1.75	1.6	1.38	0.76	--	1.16	1.67	0.51	0.393	--	--
16, 27, 50	16	3740	27	1489	50	100	69.7	11.5	8.18	9.8	8.93	1.09	5.38	9.93	1.09	10.0	2.46	1.2
10, 20, 30	10	1460	20	816	30	100	20.0	3.61	3.28	3.0	2.29	0.73	1.96	2.54	1.09	0.71	1.38	0.78
20, 40, 80	20	5840	40	3266	80	100	116.3	22.2	16.0	18.8	11.8	3.63	5.08	12.0	2.32	2.12	3.92	--
25, 50, 100	25	9125	50	5090	100	100	240.0	44.4	49.6	28.0	16.8	17.7	3.26	11.2	5.83	5.18	7.01	--
							3 ft from Vibrators			13 ft from Vibrators			33 ft from Vibrators			88 ft from Vibrators		
30					30	50	4.37	4.04	2.31	0.8	1.15	0.15	0.65	0.58	0.36	0.31	0.80	--
40					40	50	2.40	1.45	--	0.60	1.45	--	0.58	0.29	--	--	--	--
30, 40					30, 40	50, 50	3.14	2.63	2.01	1.0	1.68	--	0.75	0.73	0.22	0.24	0.80	--



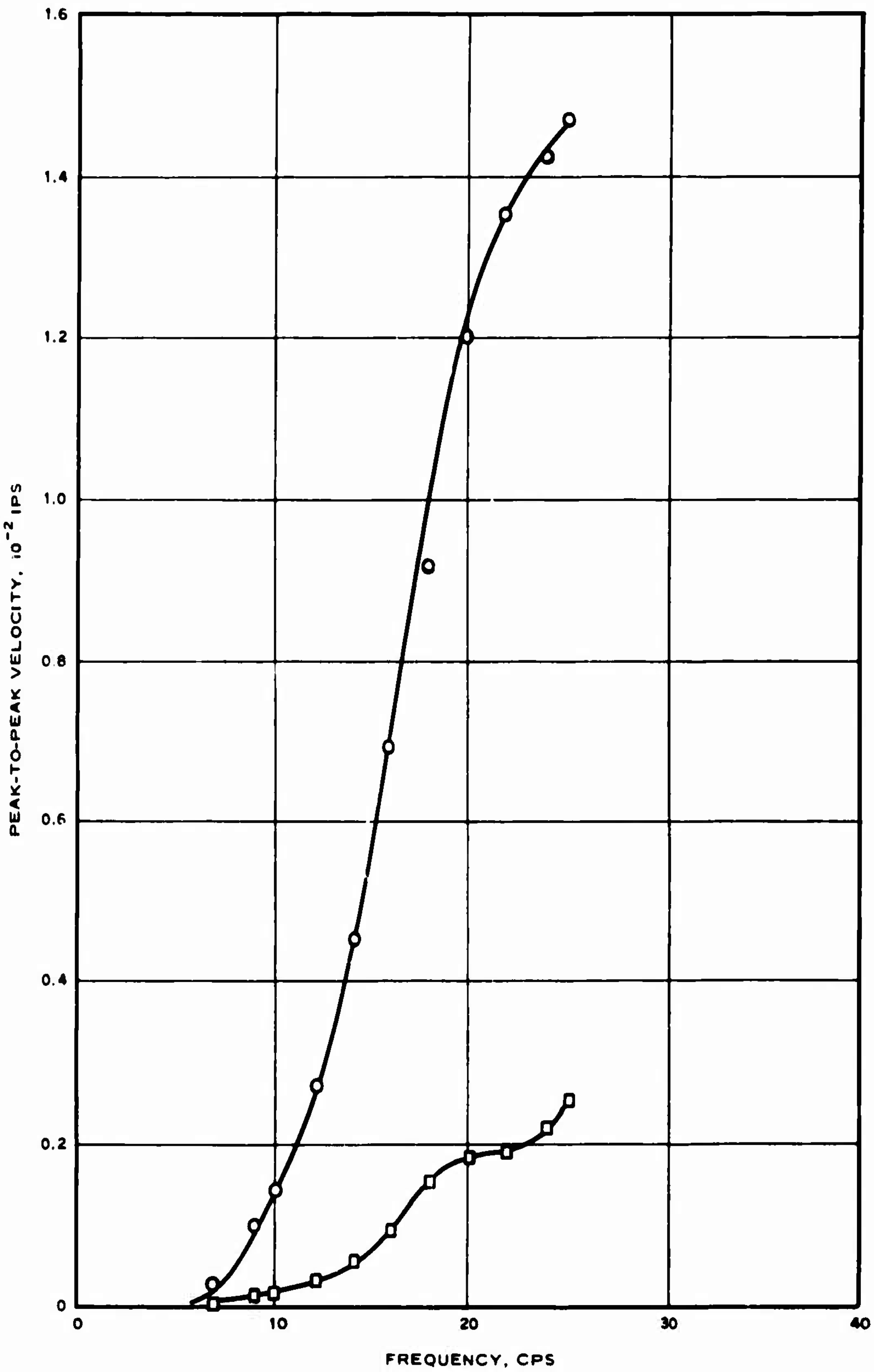
Photograph 1. Northeast view of four vibrators mounted on concrete base



Photograph 2. Southwest view of four vibrators mounted on concrete base



Photograph 3. Setup for tests using the electromagnetic vibrators on the ground surface



VERTICAL PICKUP

O ON THE BASE

□ 15 FT FROM THE BASE

PEAK-TO-PEAK VELOCITY VS FREQUENCY

DTMB VIBRATOR
0.1-IN. ECCENTRICITY

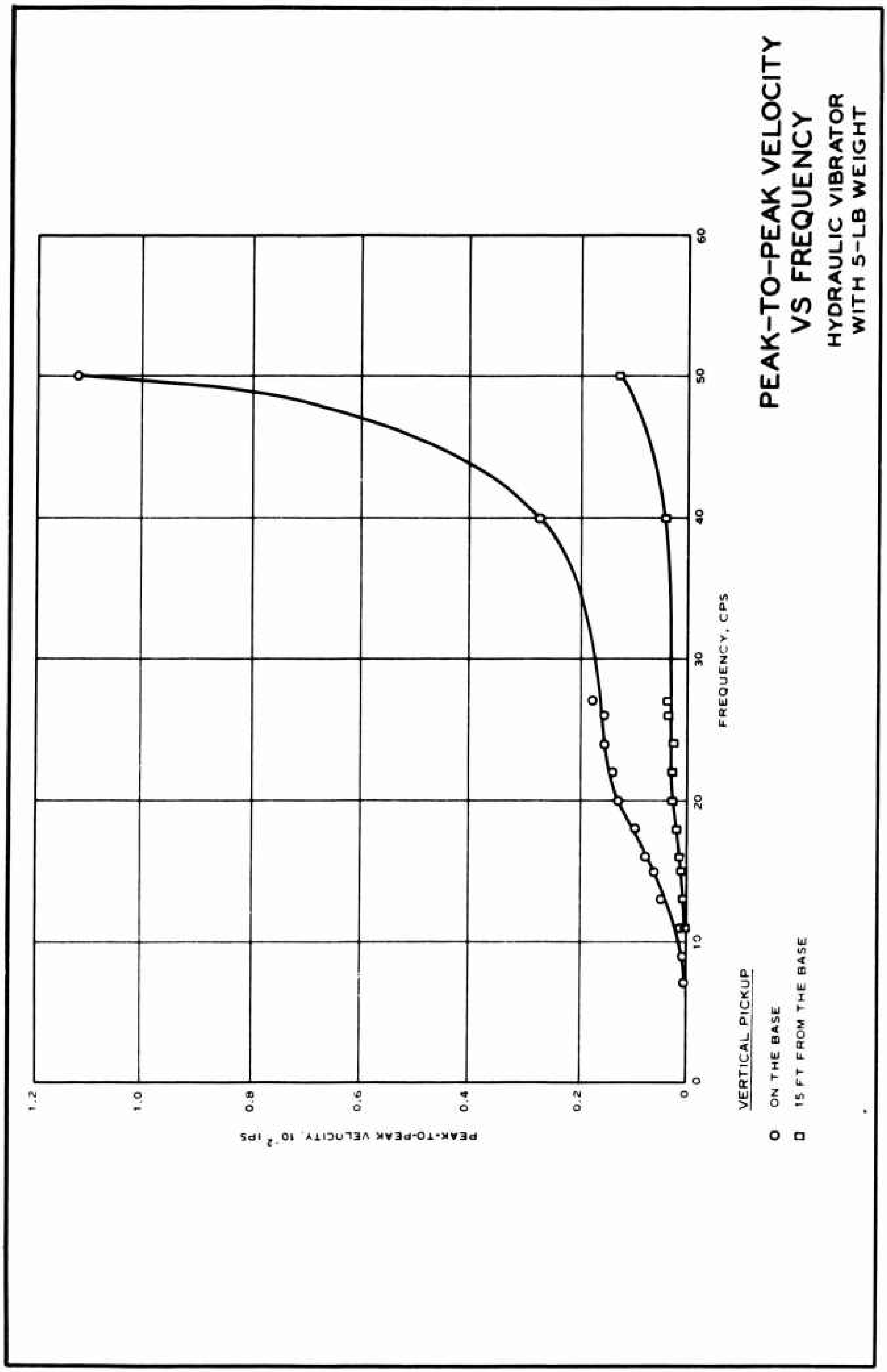
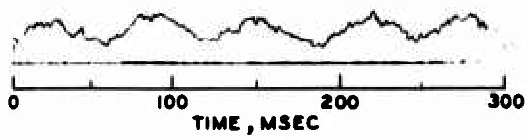
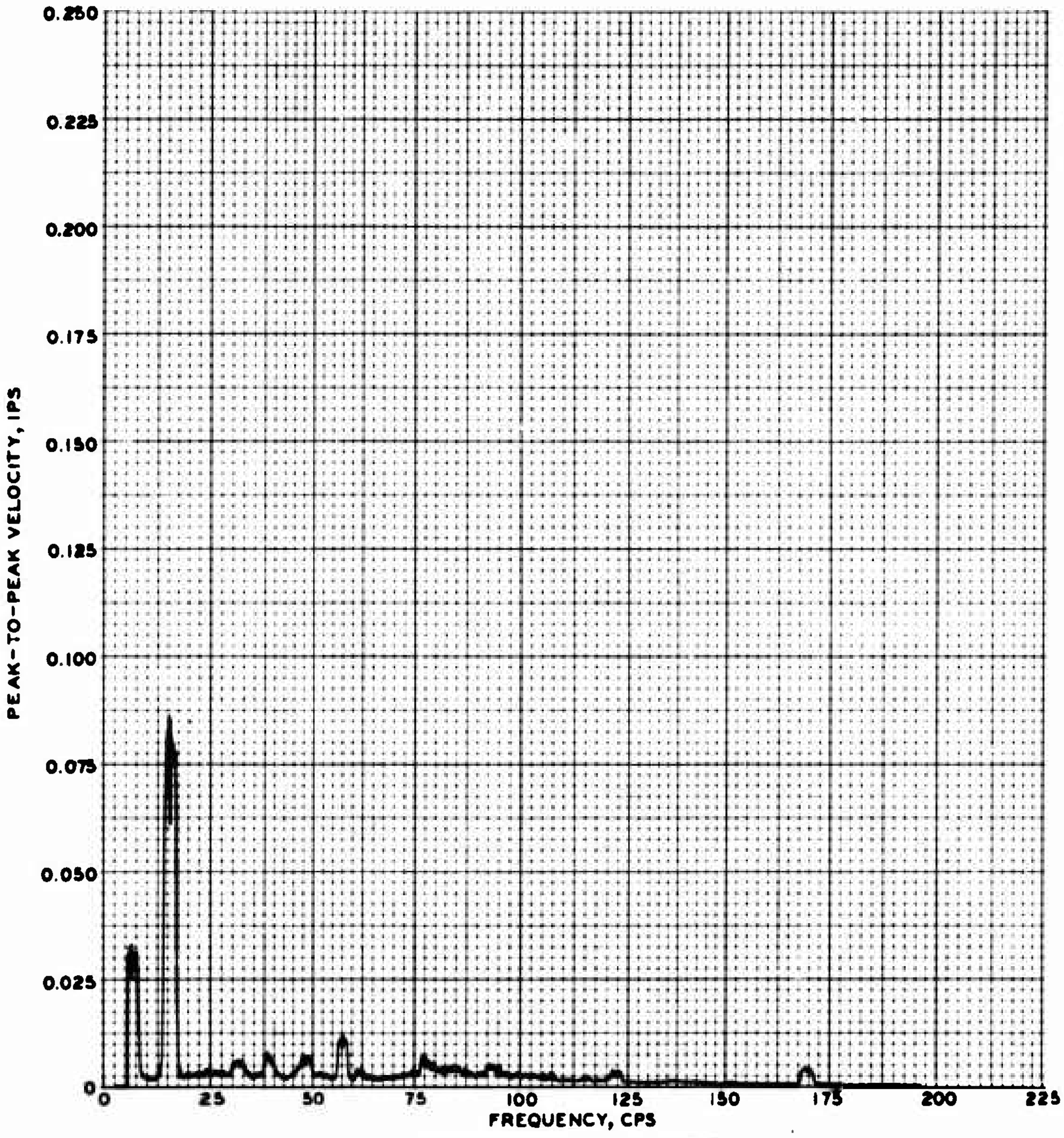

PEAK-TO-PEAK VELOCITY
VS FREQUENCY
HYDRAULIC VIBRATOR
WITH 5-LB WEIGHT
PEAK-TO-PEAK VELOCITY, 10⁻² IPS
FREQUENCY, CPS
0
0.2
0.4
0.6
0.8
1.0
1.2
0
10
20
30
40
50
60
VERTICAL PICKUP
ON THE BASE
15 FT FROM THE BASE

PLATE 2



ACTUAL WAVE SHAPE



SPECTRUM ANALYSIS

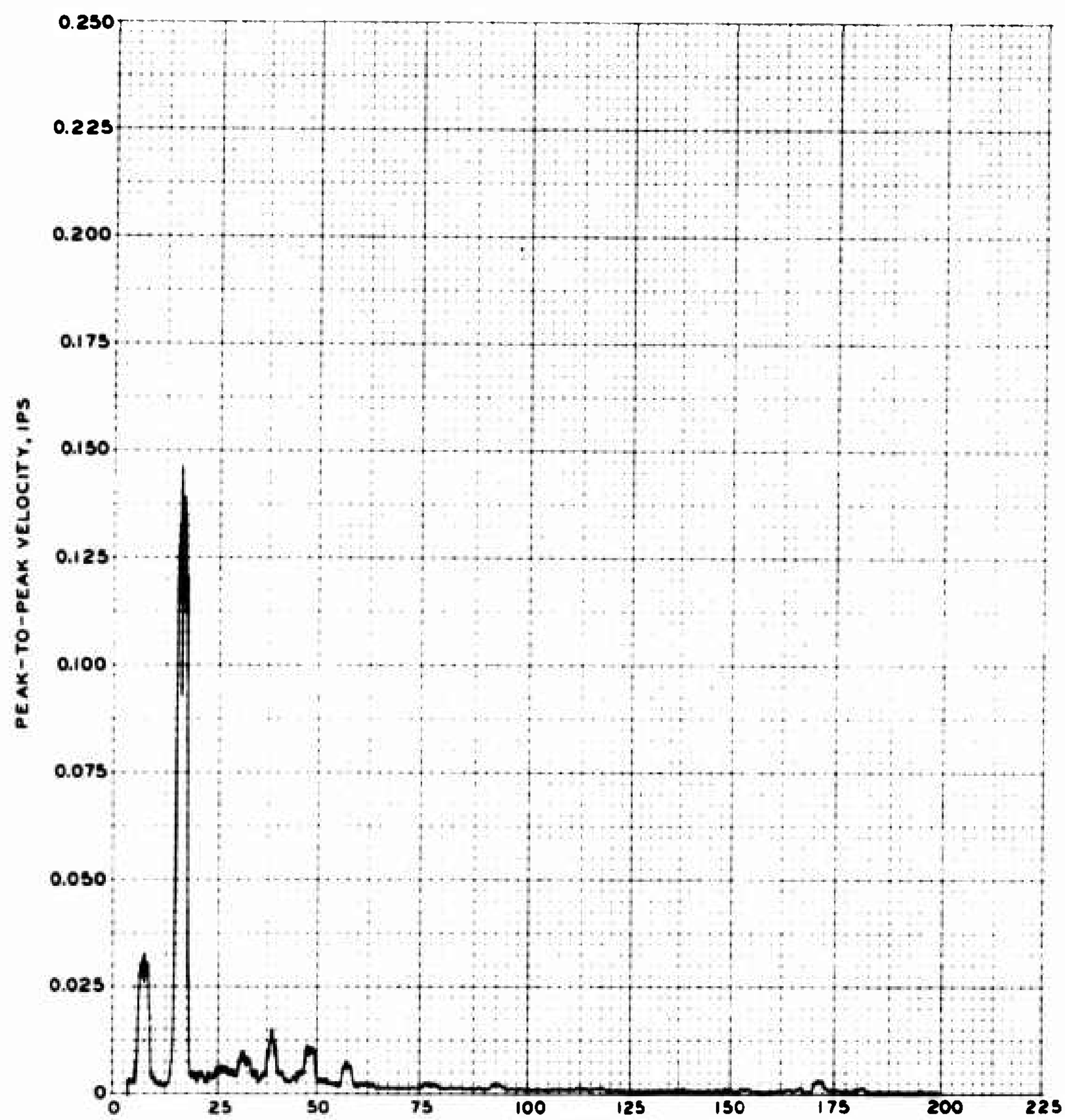
VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	7	715
HYDRAULIC	16	523
ELECTROMAGNETIC	50	100

FREQUENCY SPECTRUM ANALYSIS

RUN 34

VERTICAL PICKUP ON CONCRETE BASE

ACTUAL WAVE SHAPE



SPECTRUM ANALYSIS

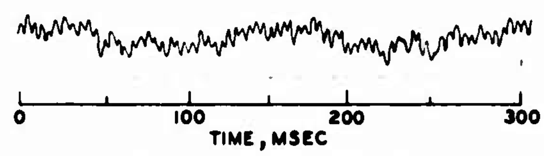
VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	7	715
HYDRAULIC	16	523
ELECTROMAGNETIC	50	100

FREQUENCY SPECTRUM ANALYSIS

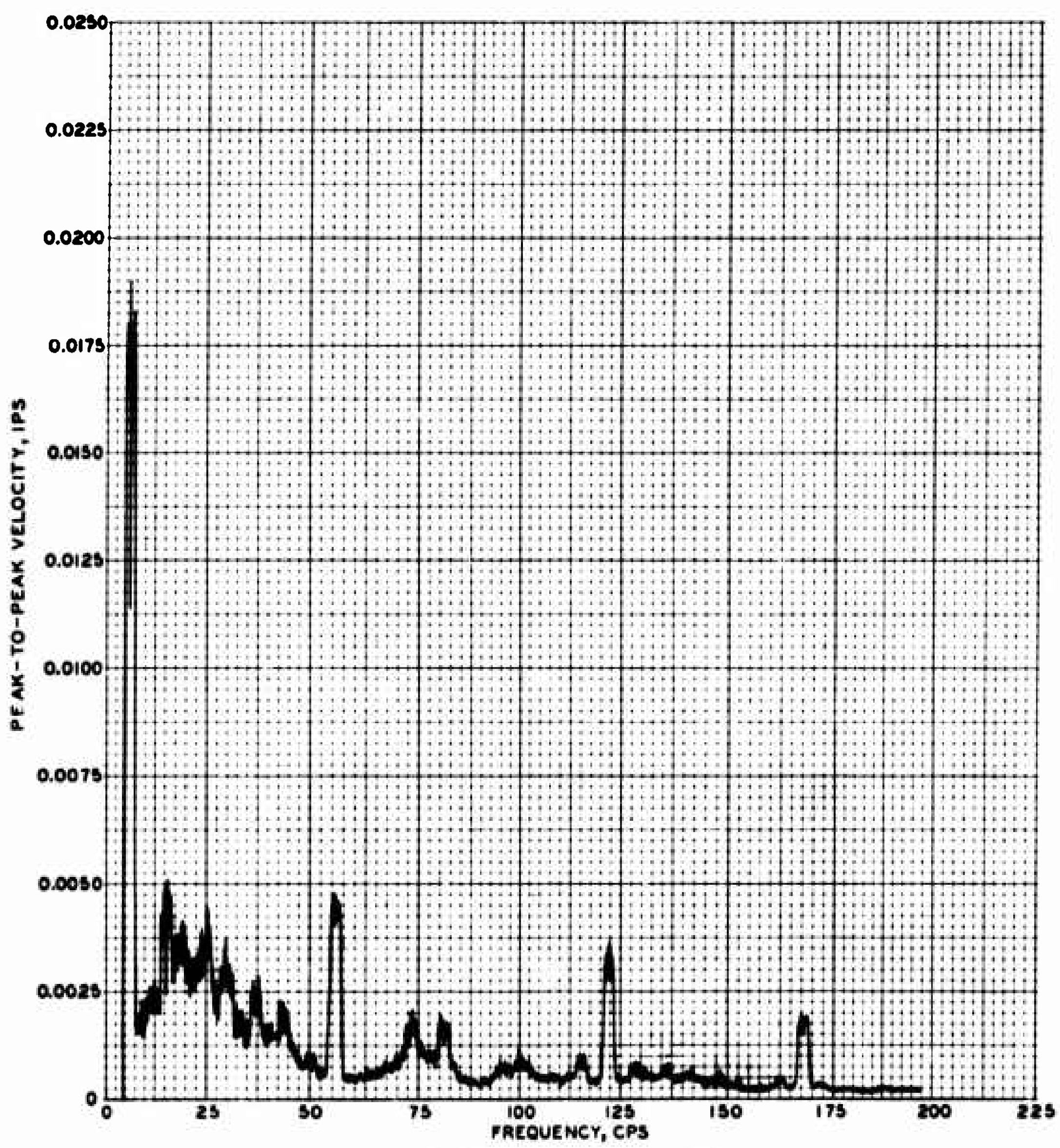
RUN 34

VERTICAL PICKUP 15 FT FROM CONCRETE BASE

PLATE 4



ACTUAL WAVE SHAPE



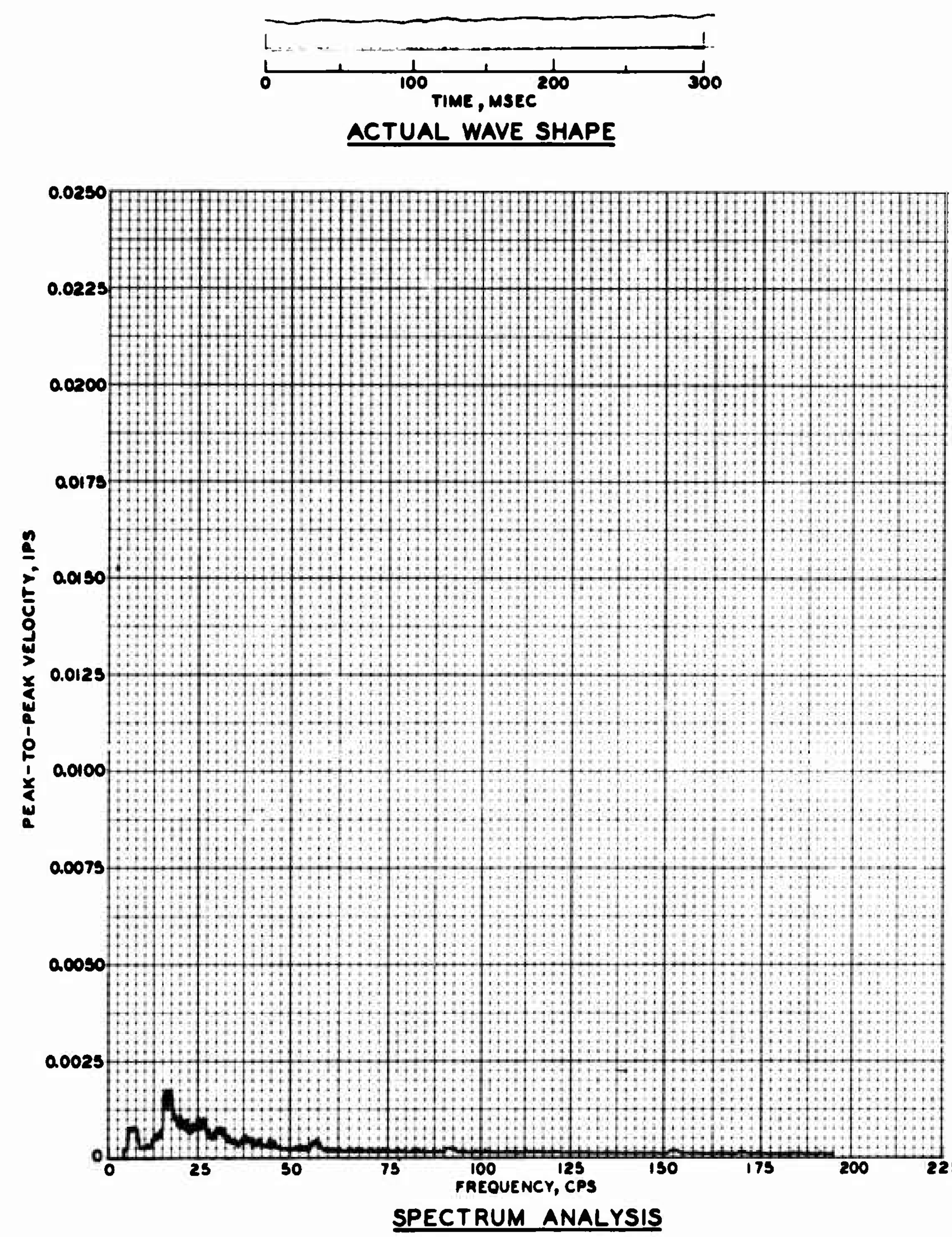
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	7	715

FREQUENCY SPECTRUM ANALYSIS

RUN 11

VERTICAL PICKUP ON CONCRETE BASE

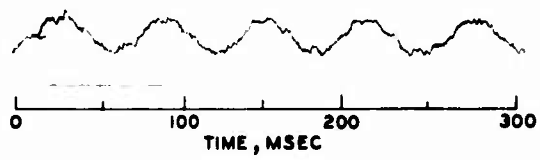


VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	7	715

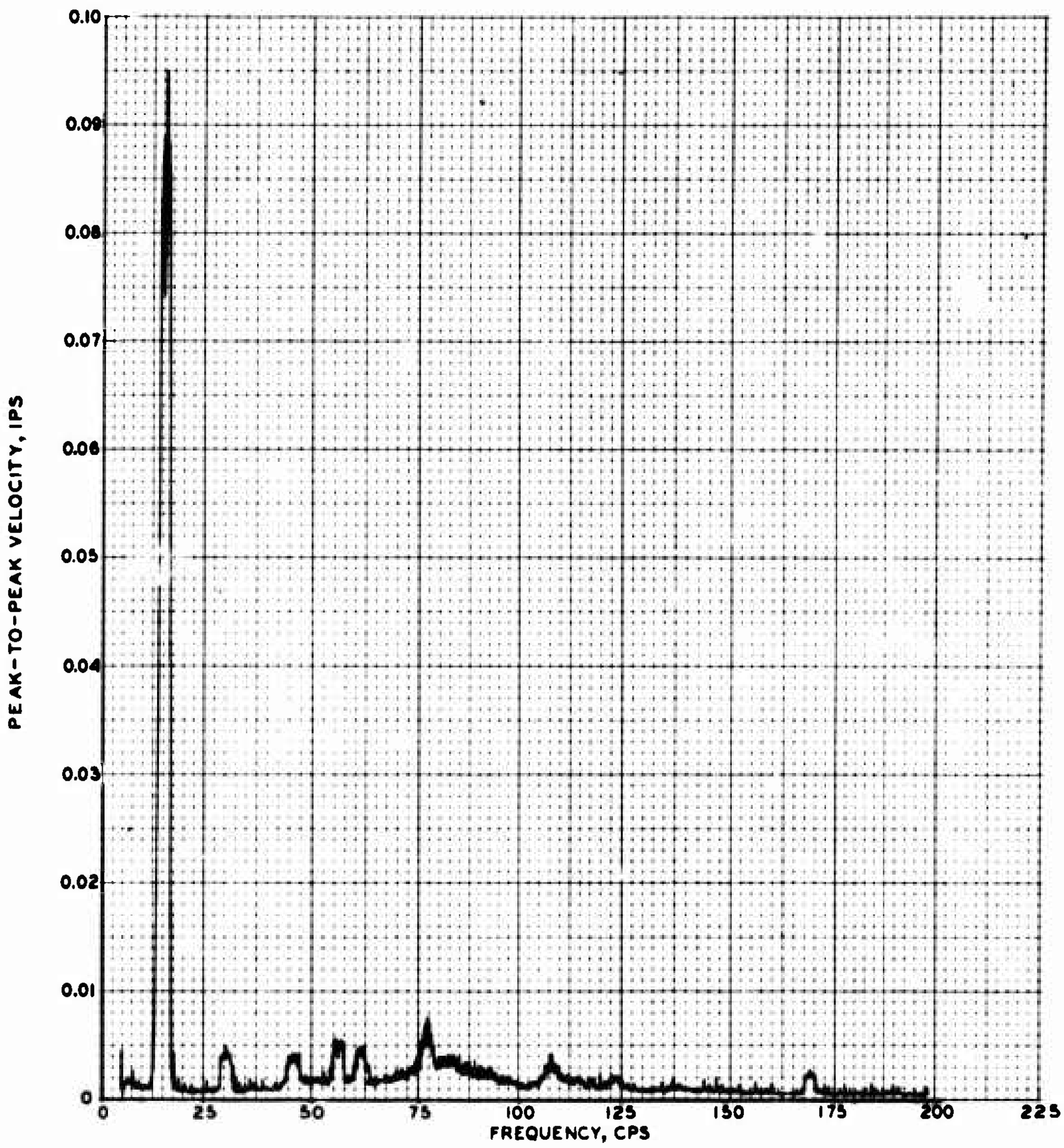
FREQUENCY SPECTRUM ANALYSIS

RUN 11

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



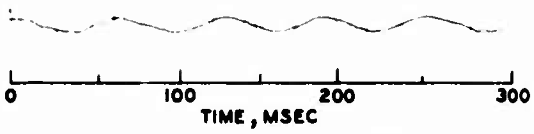
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
HYDRAULIC	16	523

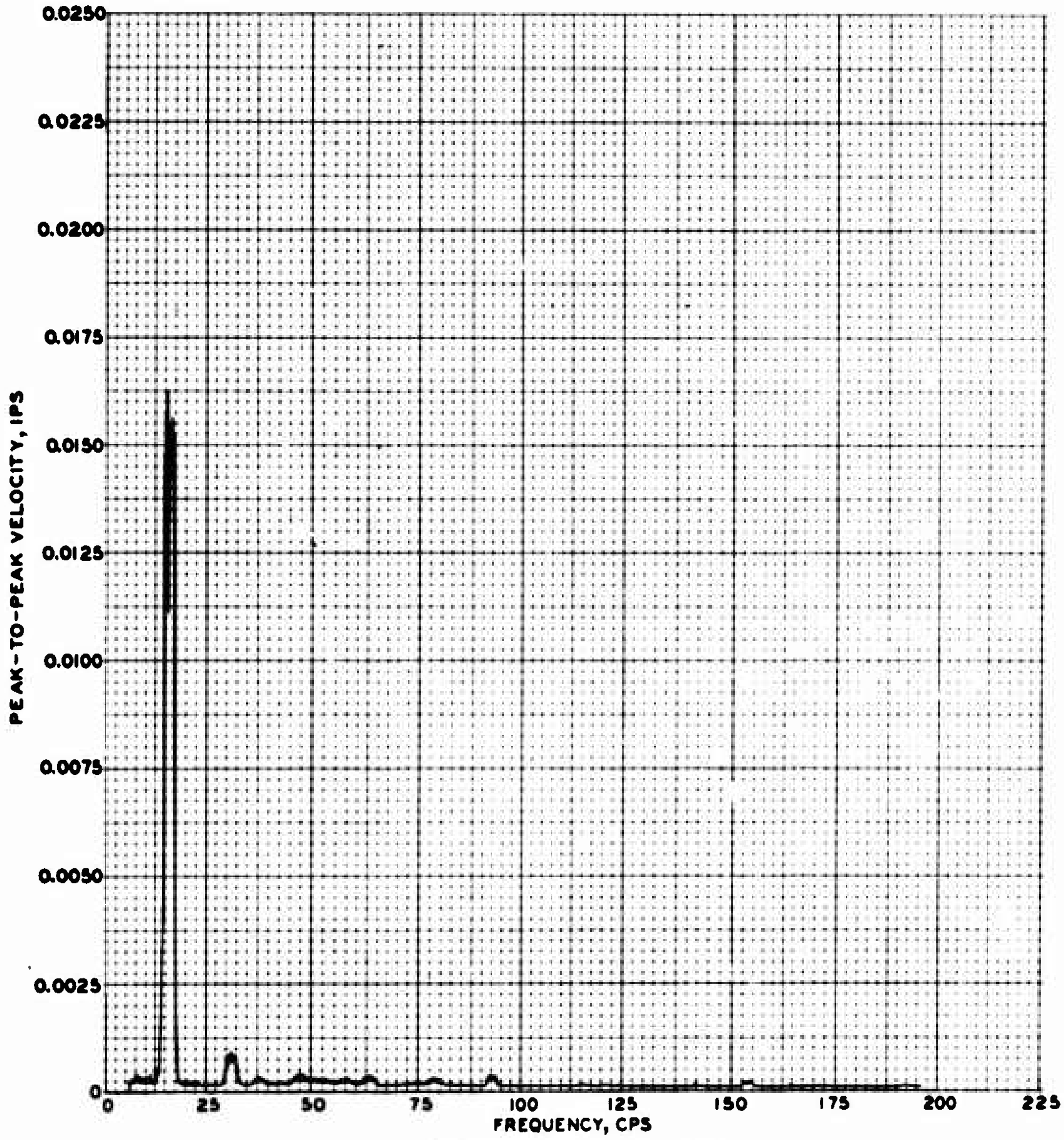
FREQUENCY SPECTRUM ANALYSIS

RUN 17

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



SPECTRUM ANALYSIS

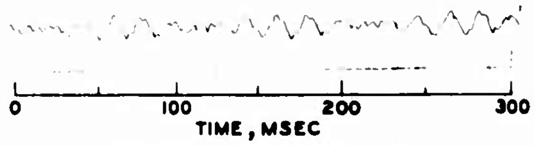
VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
HYDRAULIC	16	523

FREQUENCY SPECTRUM ANALYSIS

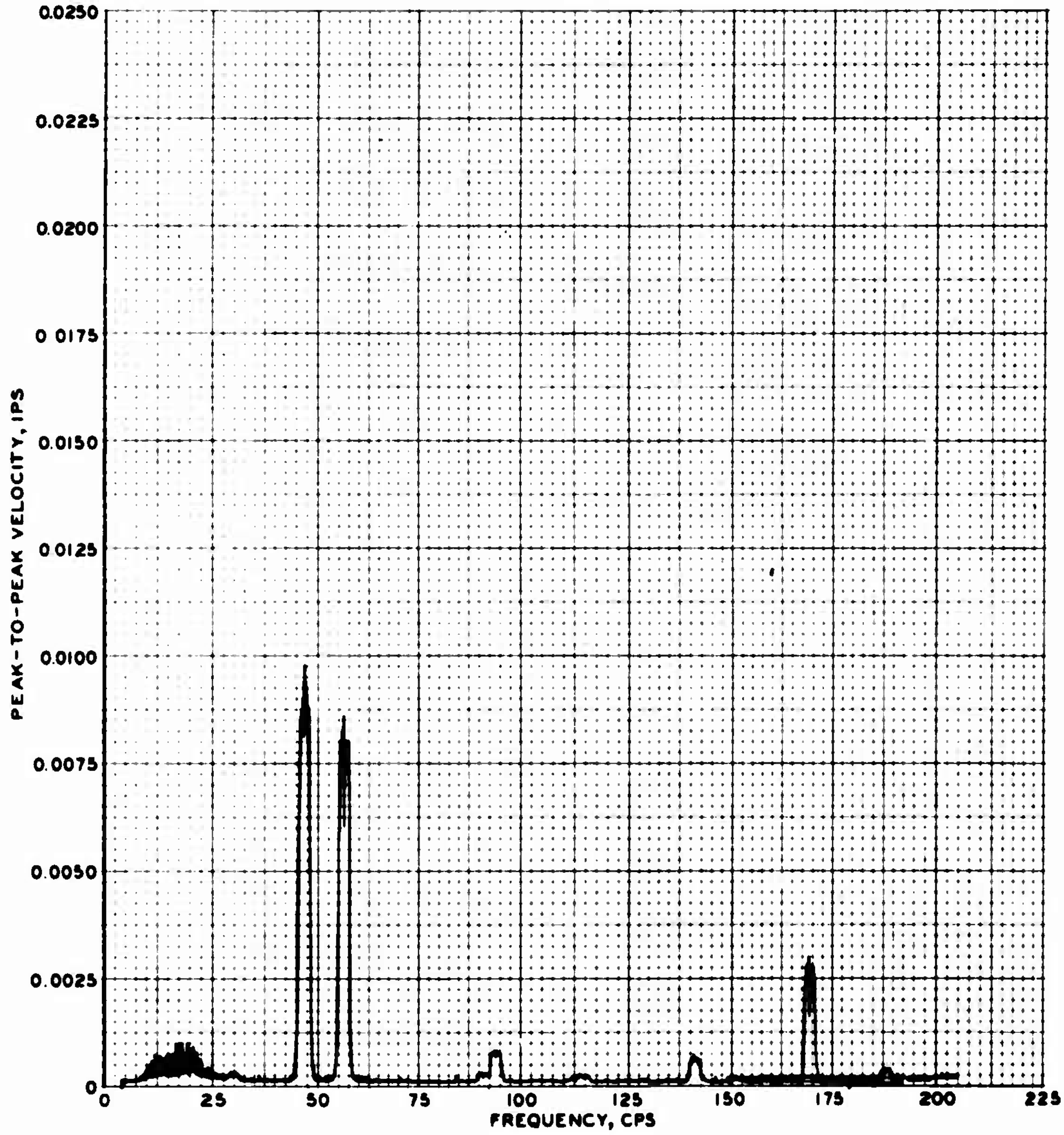
RUN 17

VERTICAL PICKUP 15 FT FROM CONCRETE BASE

PLATE 8



ACTUAL WAVE SHAPE



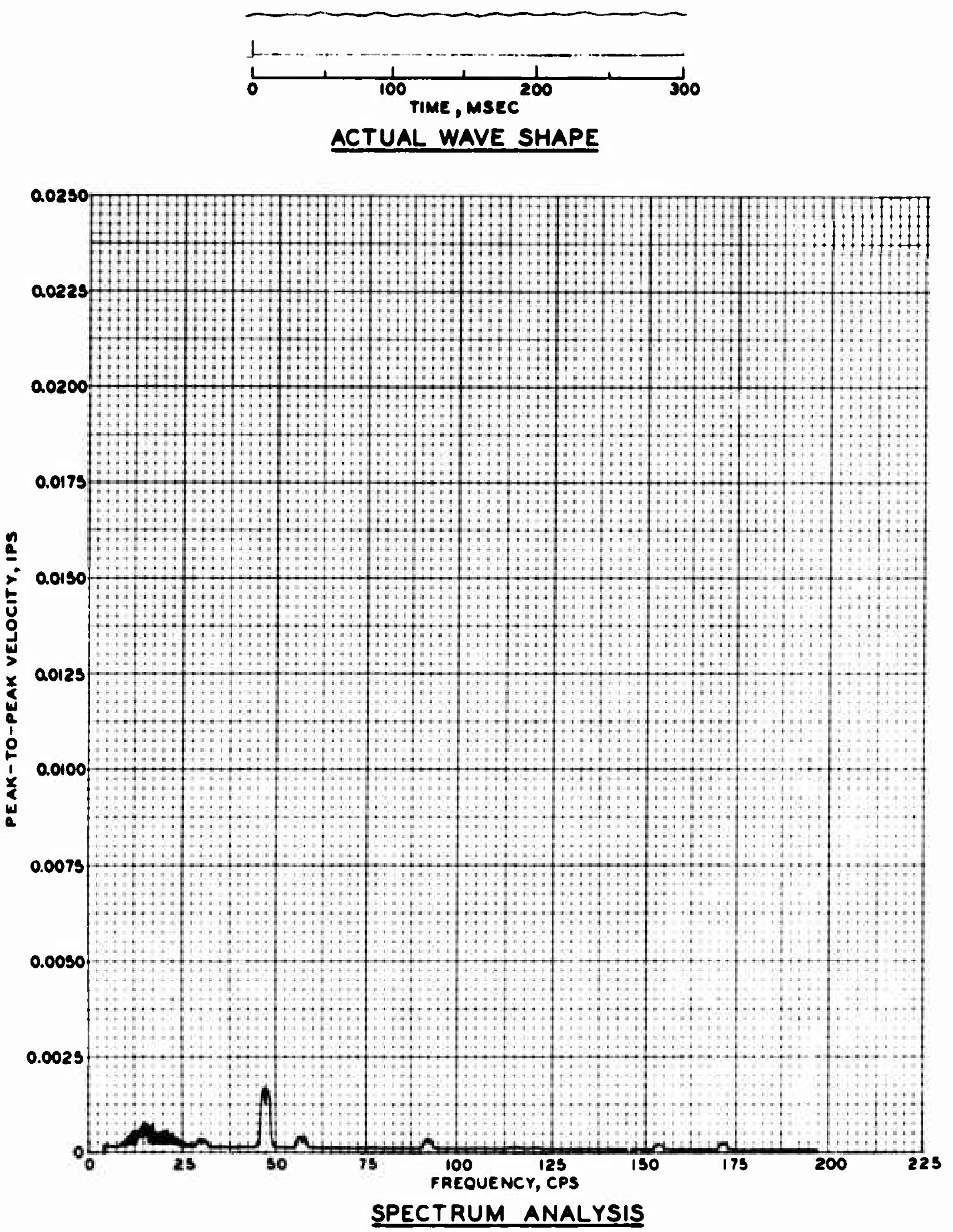
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	50	100

FREQUENCY SPECTRUM ANALYSIS

RUN 28

VERTICAL PICKUP ON CONCRETE BASE

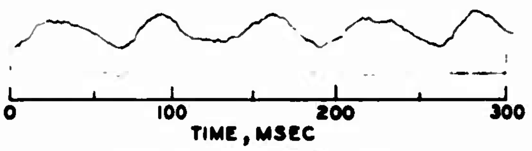


VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	50	100

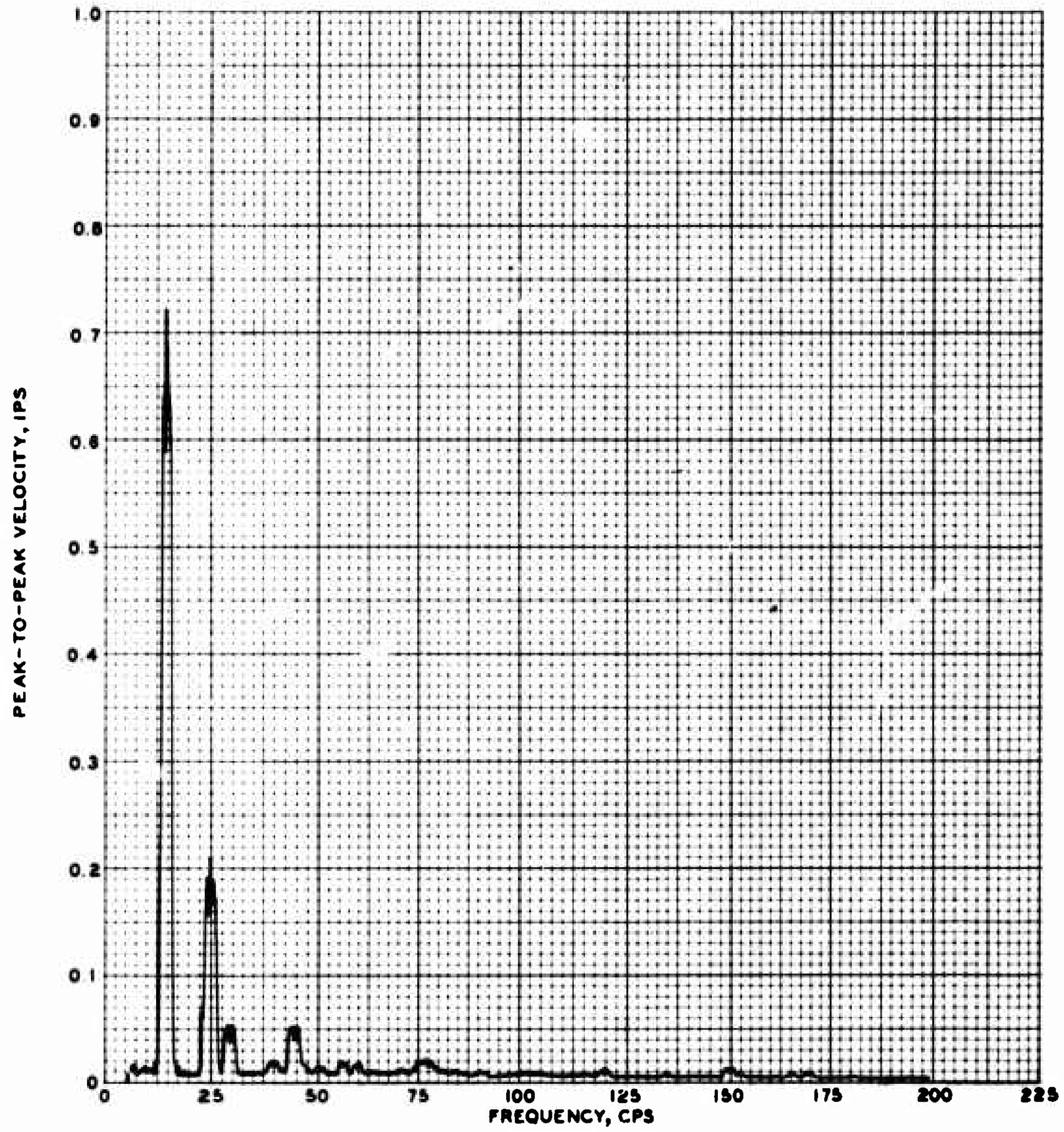
FREQUENCY SPECTRUM ANALYSIS

RUN 28

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



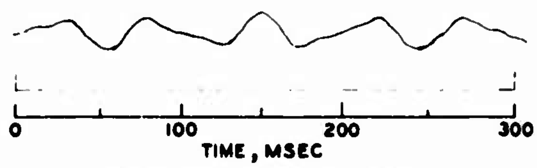
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	16	3740
HYDRAULIC	27	1489
ELECTROMAGNETIC	50	100

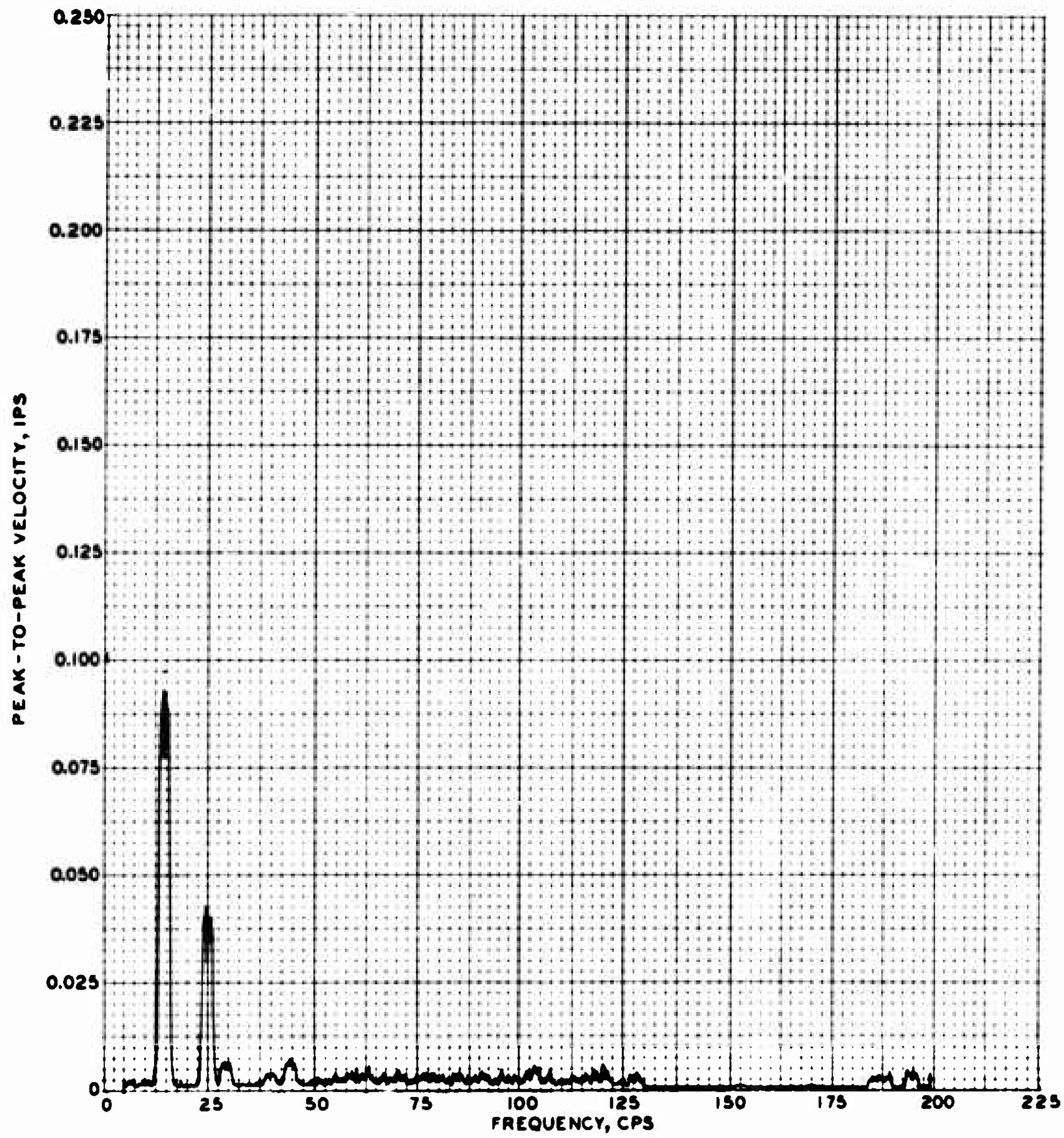
FREQUENCY SPECTRUM ANALYSIS

RUN 35

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



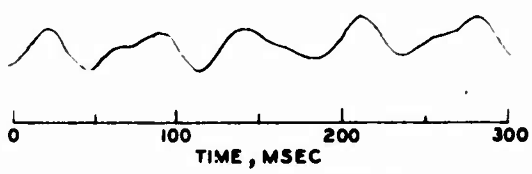
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	18	3740
HYDRAULIC	27	1488
ELECTROMAGNETIC	50	100

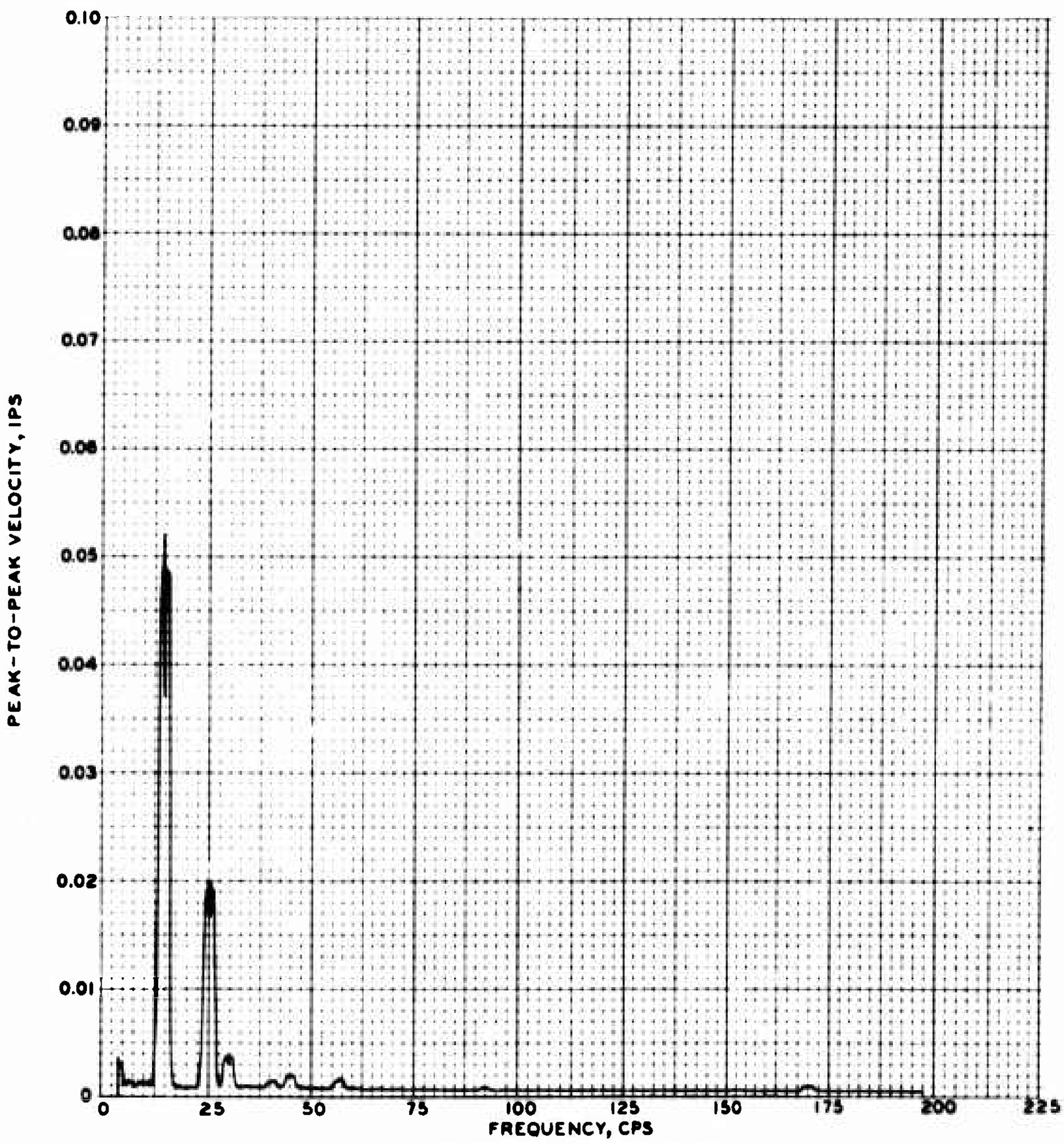
FREQUENCY SPECTRUM ANALYSIS

RUN 35

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



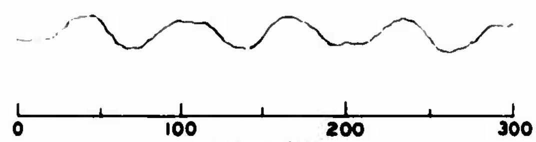
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	16	3740
HYDRAULIC	27	1489
ELECTROMAGNETIC	50	100

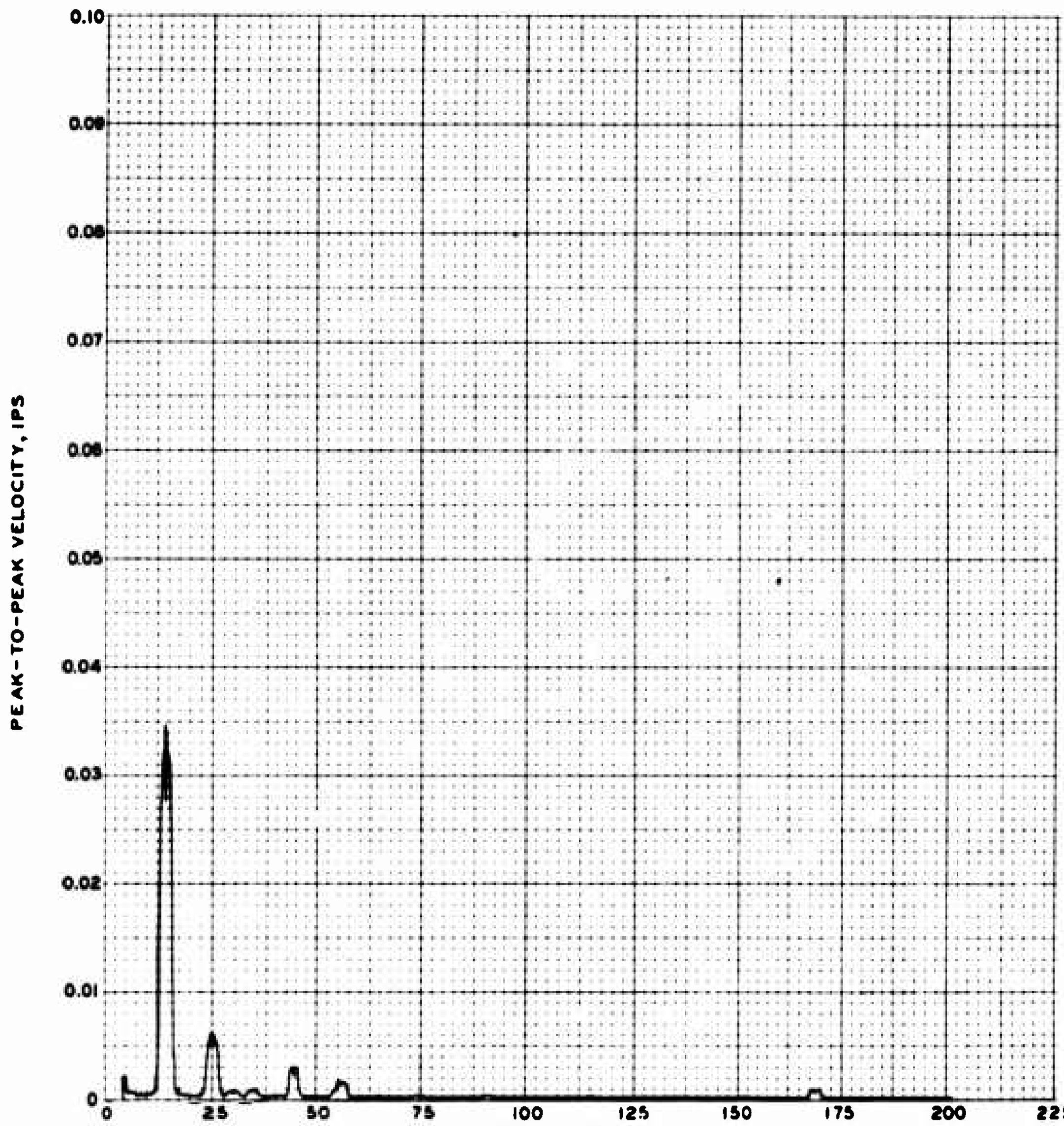
FREQUENCY SPECTRUM ANALYSIS

RUN 35

VERTICAL PICKUP 35 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



SPECTRUM ANALYSIS

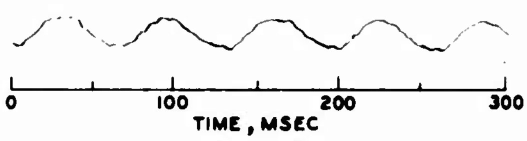
VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	16	3740
HYDRAULIC	27	1489
ELECTROMAGNETIC	50	100

FREQUENCY SPECTRUM ANALYSIS

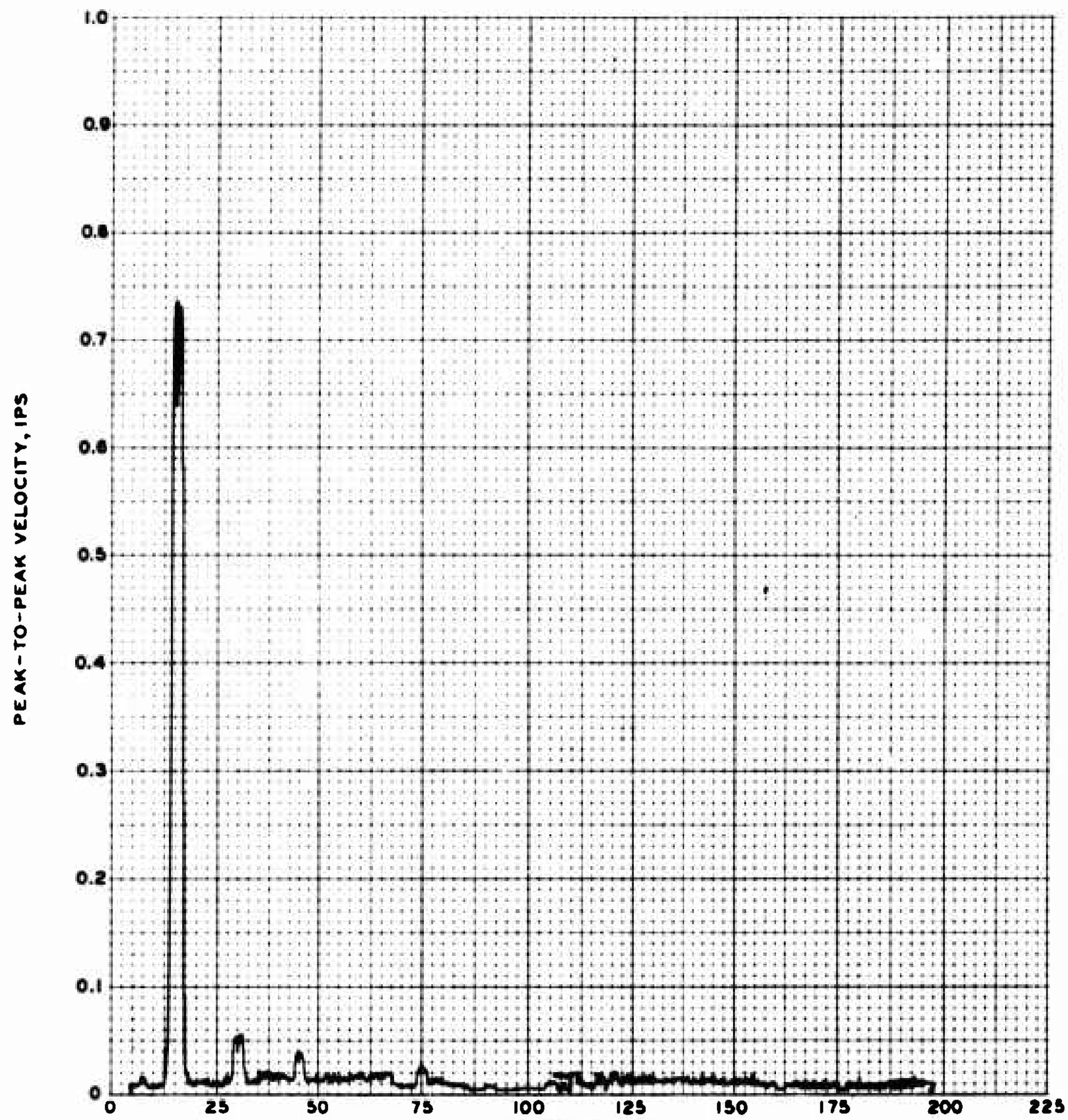
RUN 35

VERTICAL PICKUP 90 FT FROM CONCRETE BASE

PLATE 14



ACTUAL WAVE SHAPE



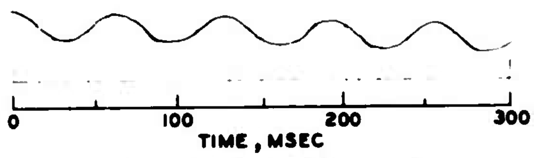
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	18	3740

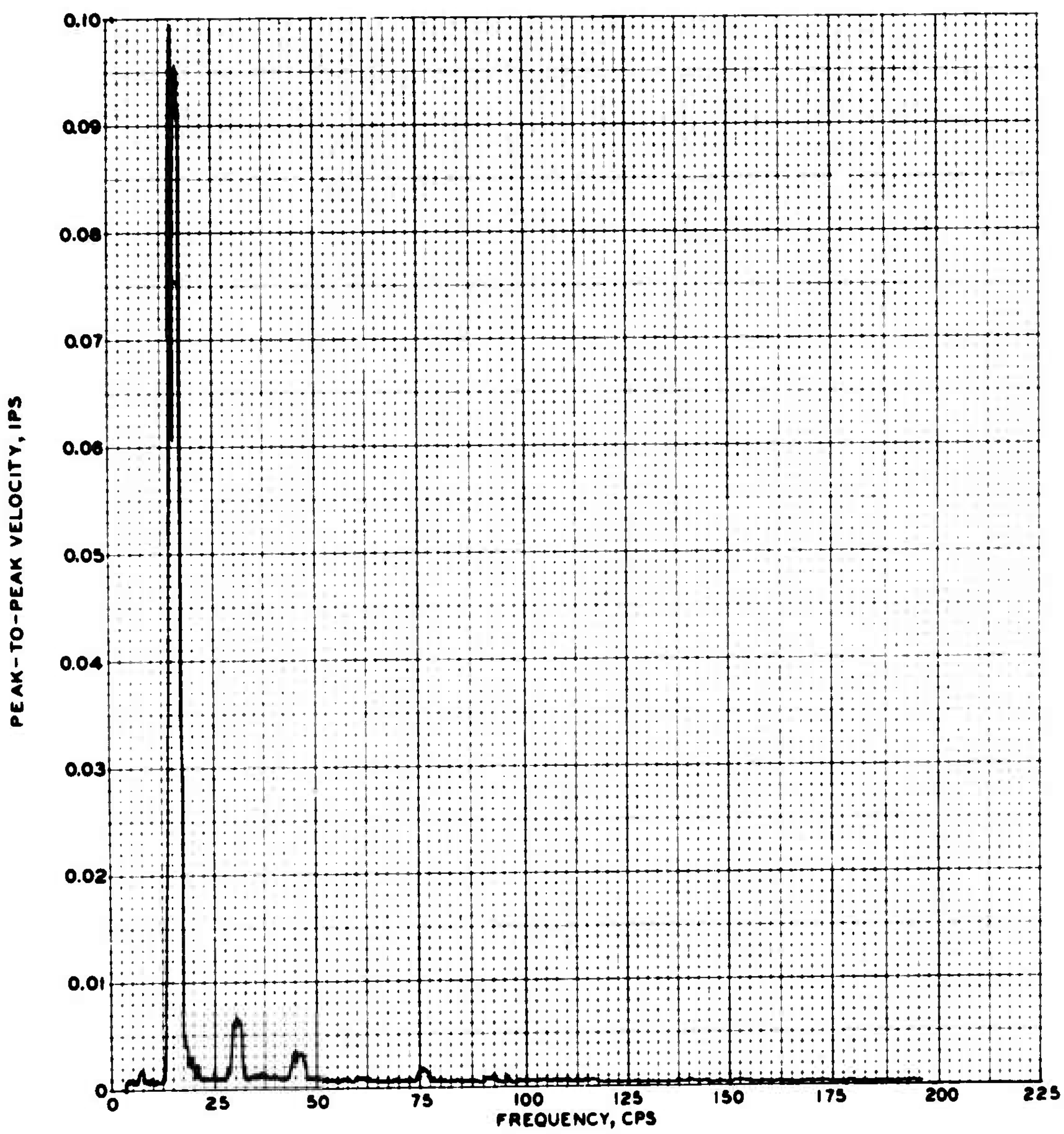
FREQUENCY SPECTRUM ANALYSIS

RUN 6

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



SPECTRUM ANALYSIS

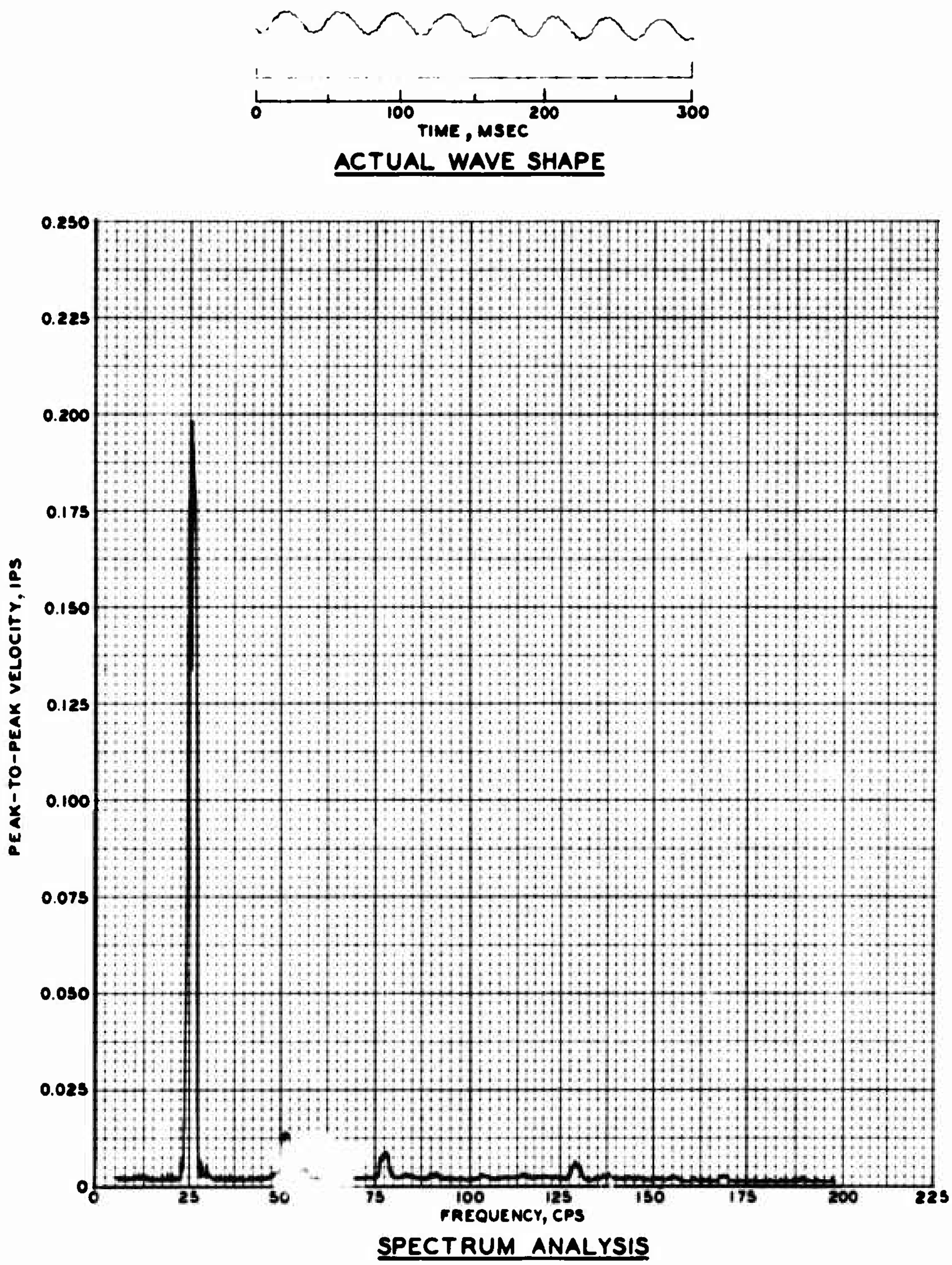
VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	16	3740

FREQUENCY SPECTRUM ANALYSIS

RUN 6

VERTICAL PICKUP 15 FT FROM CONCRETE BASE

PLATE 16

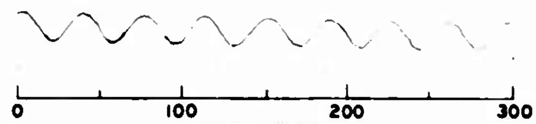


VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
HYDRAULIC	27	1489

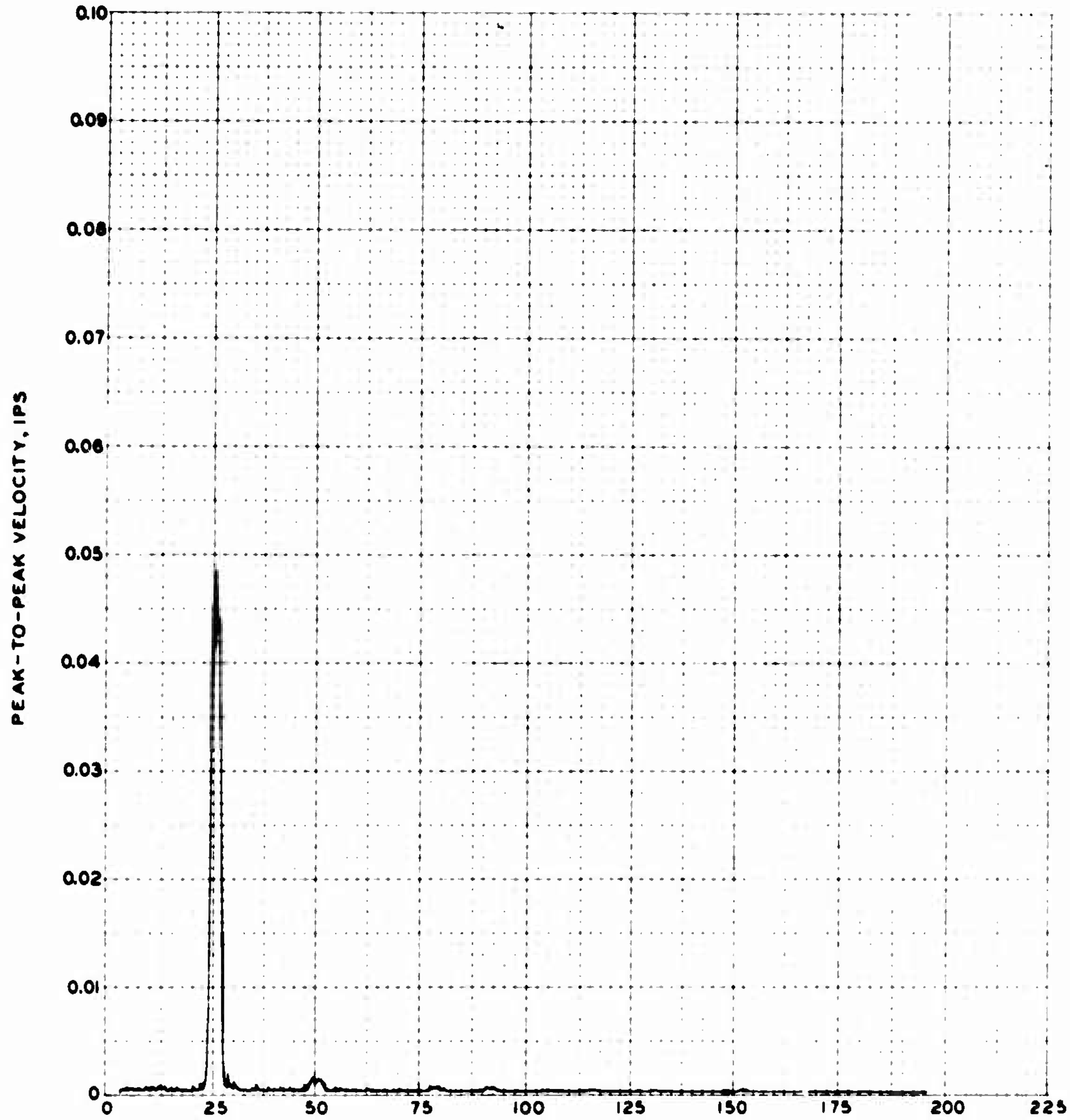
FREQUENCY SPECTRUM ANALYSIS

RUN 23

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



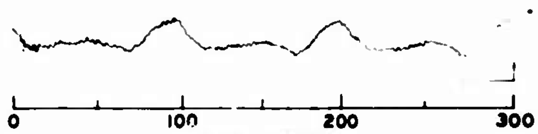
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
HYDRAULIC	27	1489

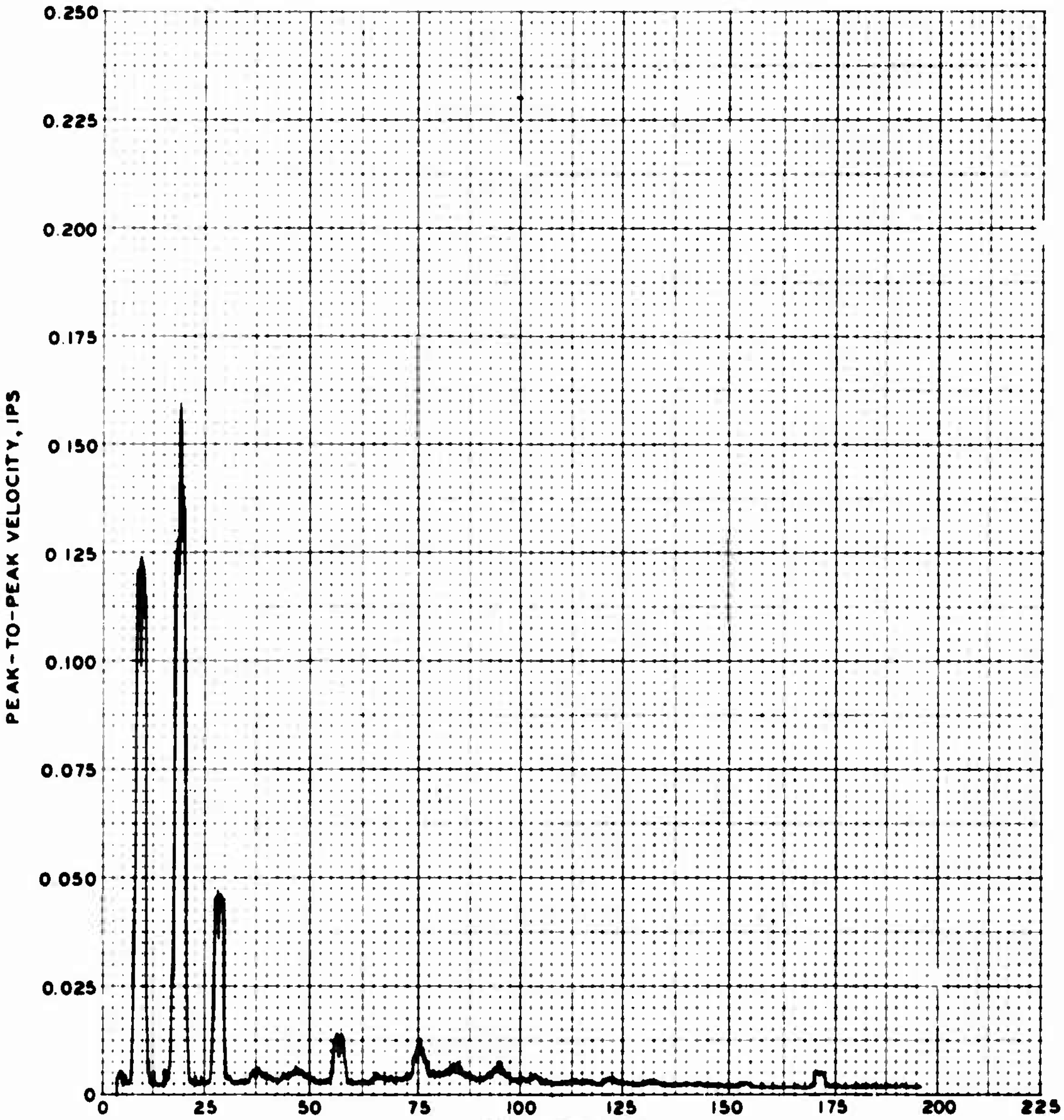
FREQUENCY SPECTRUM ANALYSIS

RUN 23

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



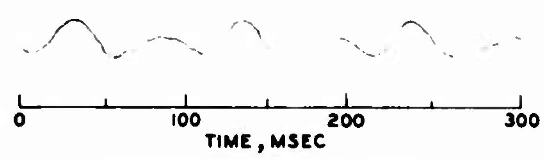
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	10	1460
HYDRAULIC	20	816
ELECTROMAGNETIC	30	100

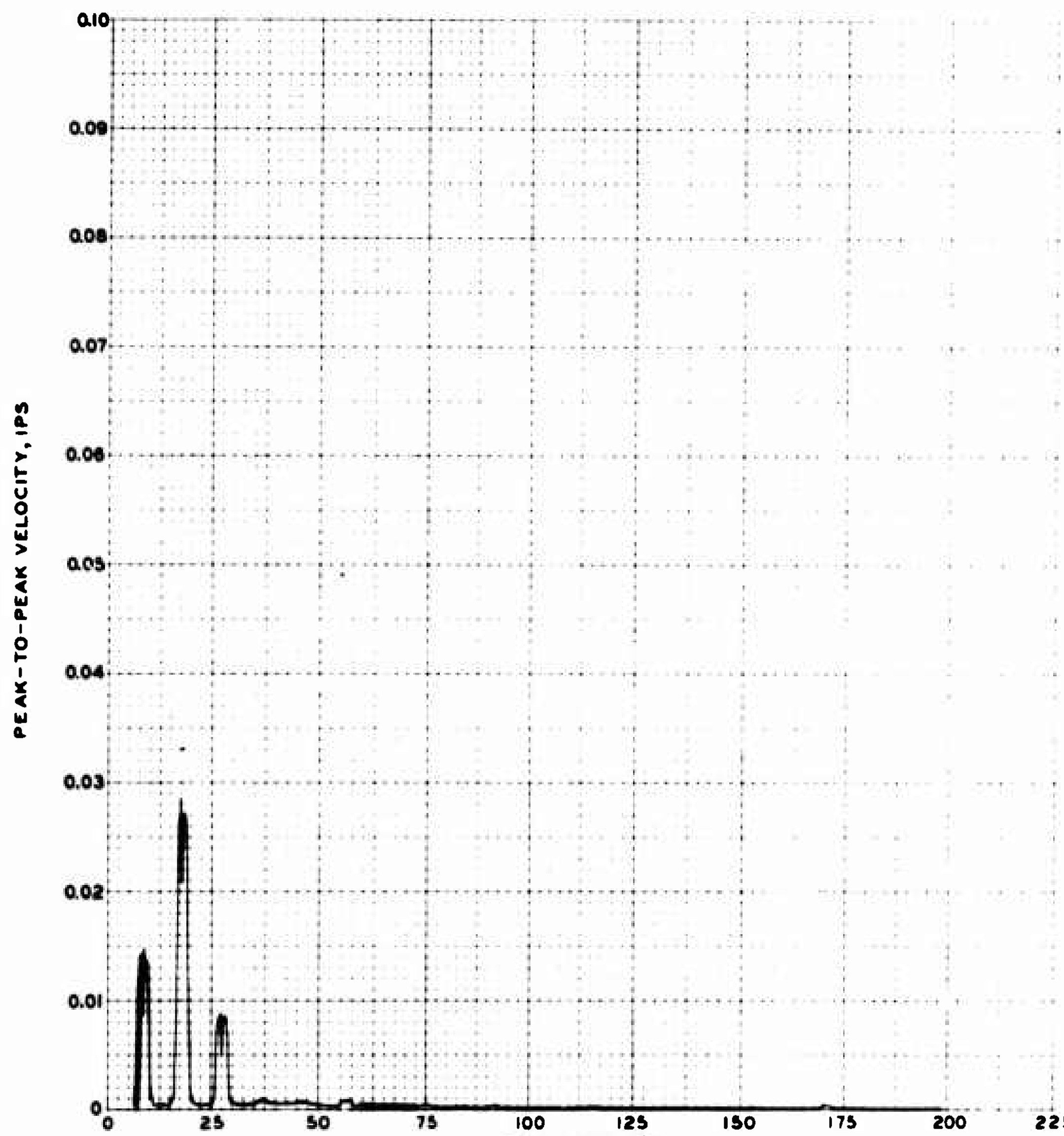
FREQUENCY SPECTRUM ANALYSIS

RUN 37

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



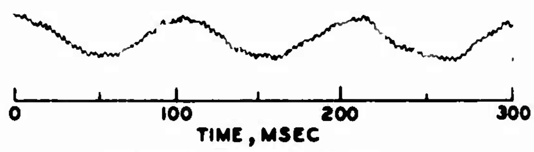
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	10	1480
HYDRAULIC	20	816
ELECTROMAGNETIC	30	100

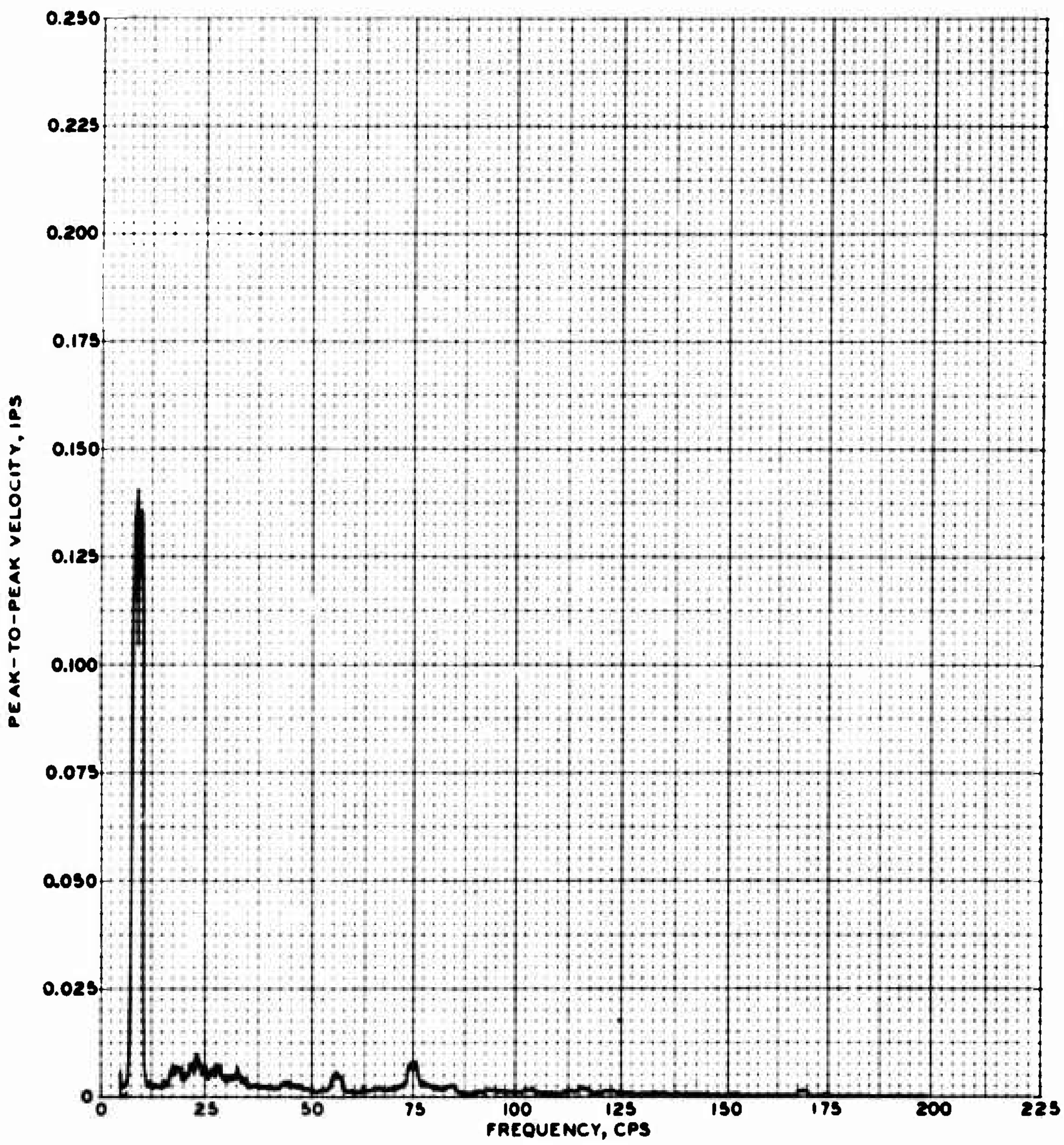
FREQUENCY SPECTRUM ANALYSIS

RUN 37

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



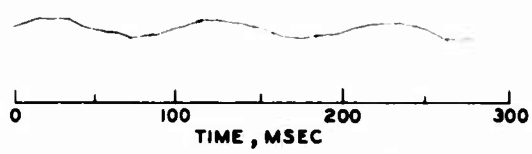
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	10	1480

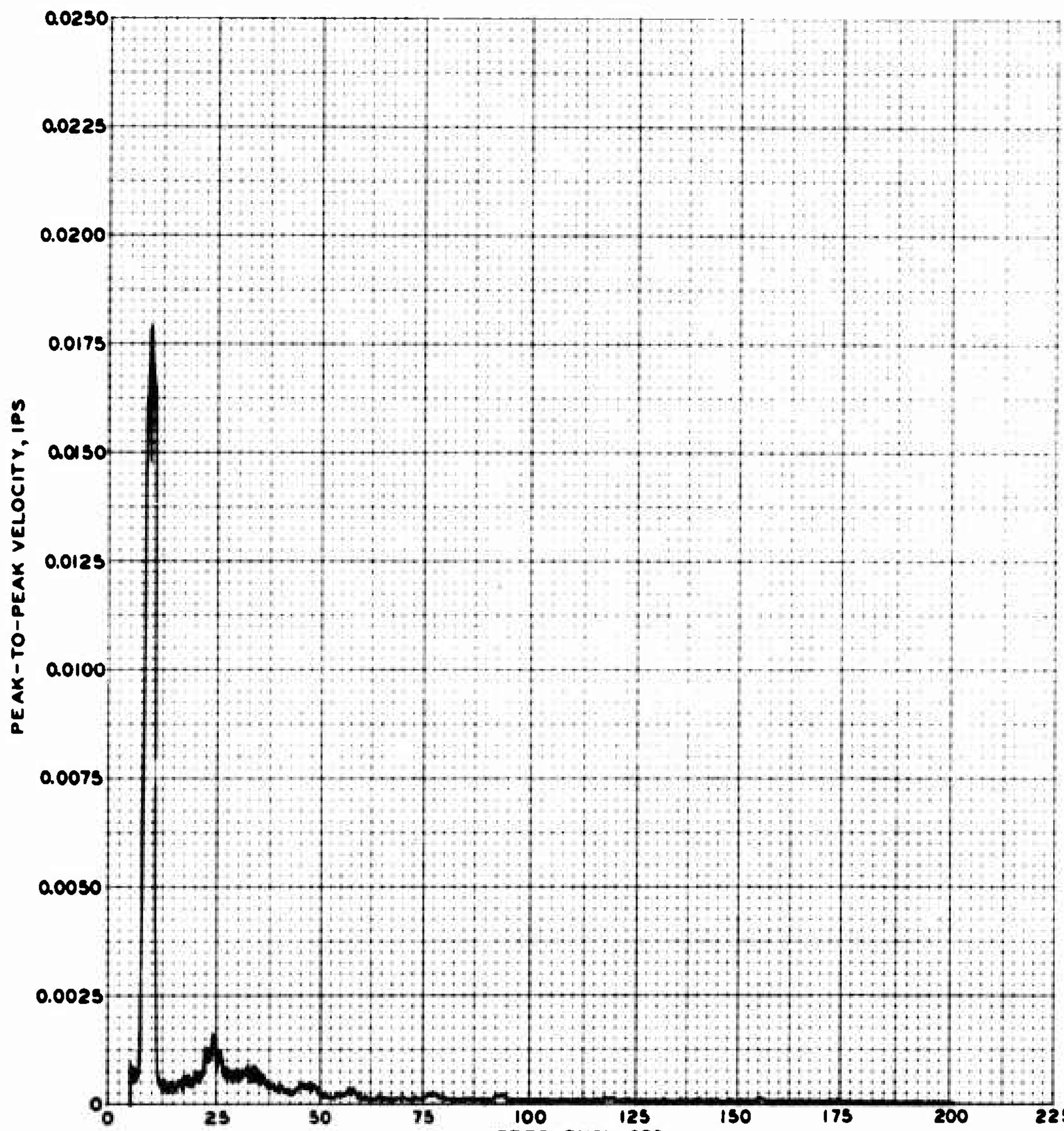
FREQUENCY SPECTRUM ANALYSIS

RUN 9

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



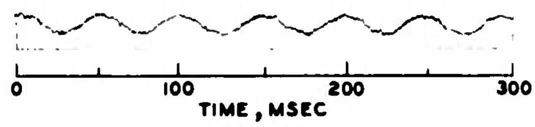
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	10	1460

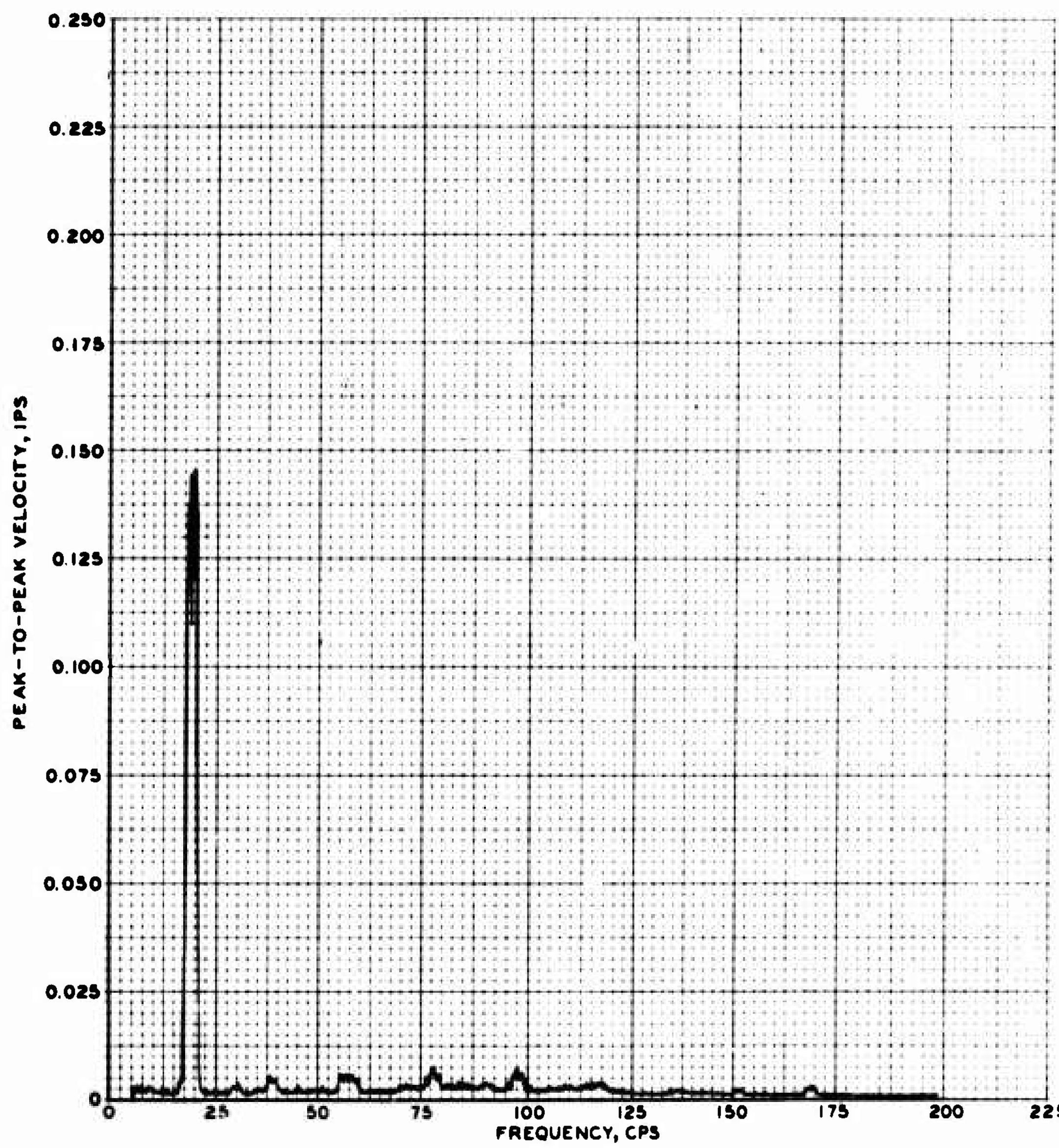
FREQUENCY SPECTRUM ANALYSIS

RUN 9

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



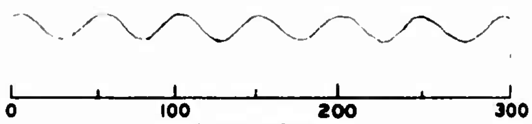
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
HYDRAULIC	20	818

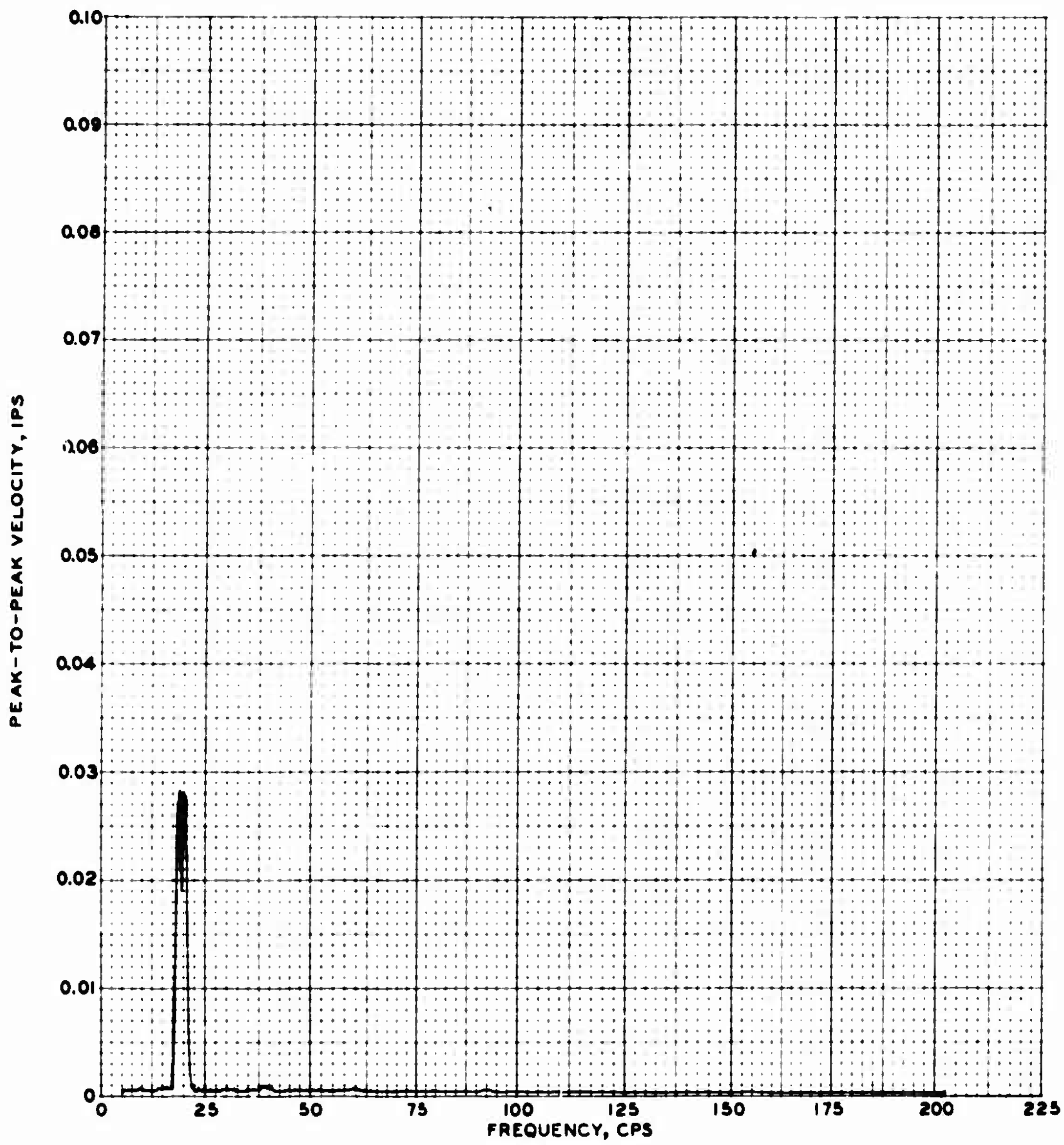
FREQUENCY SPECTRUM ANALYSIS

RUN 19

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



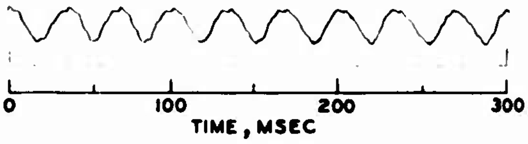
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
HYDRAULIC	20	816

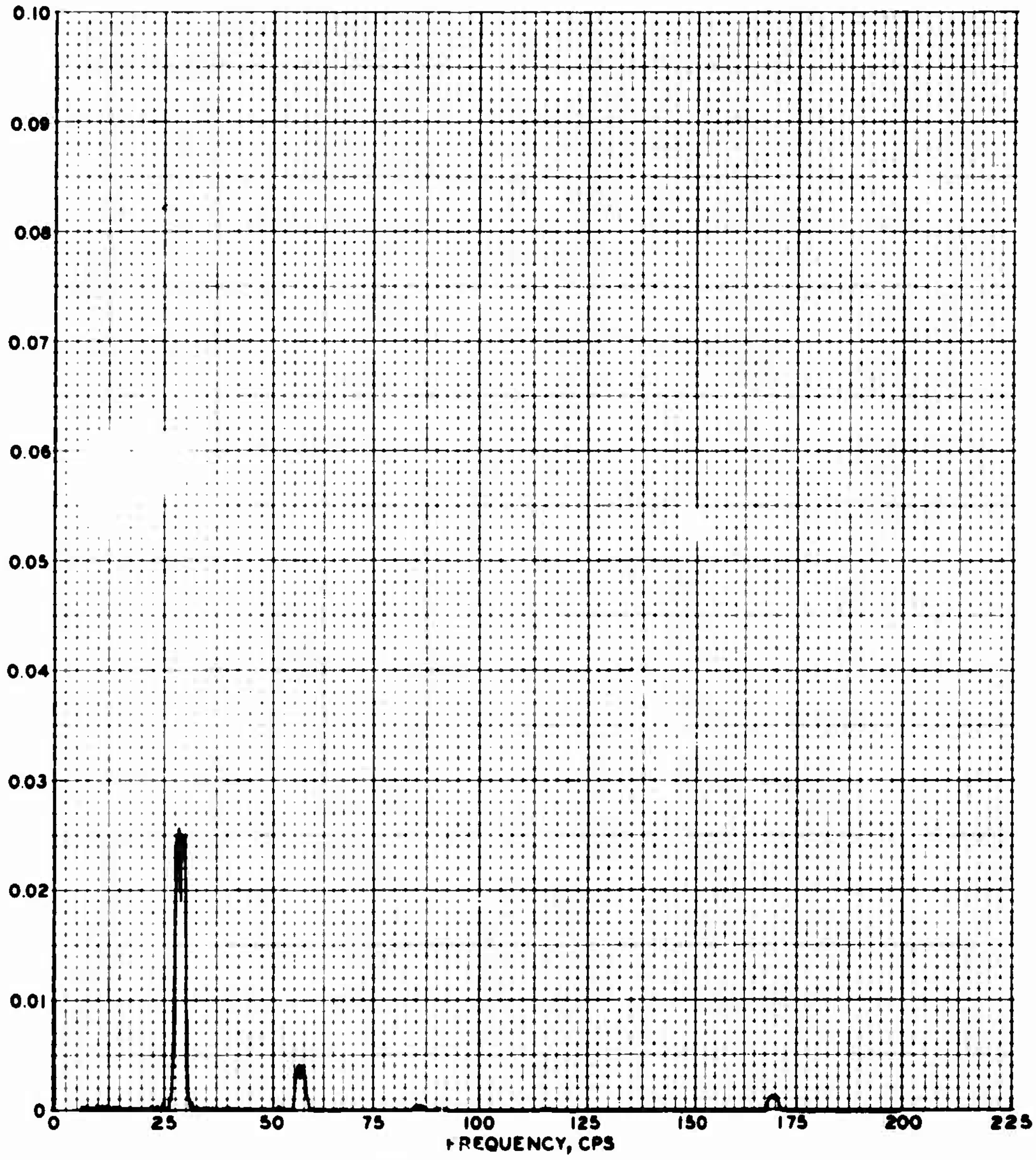
FREQUENCY SPECTRUM ANALYSIS

RUN 19

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



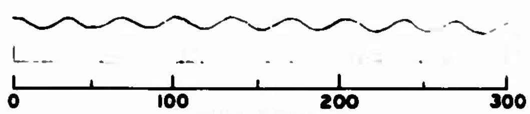
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	30	100

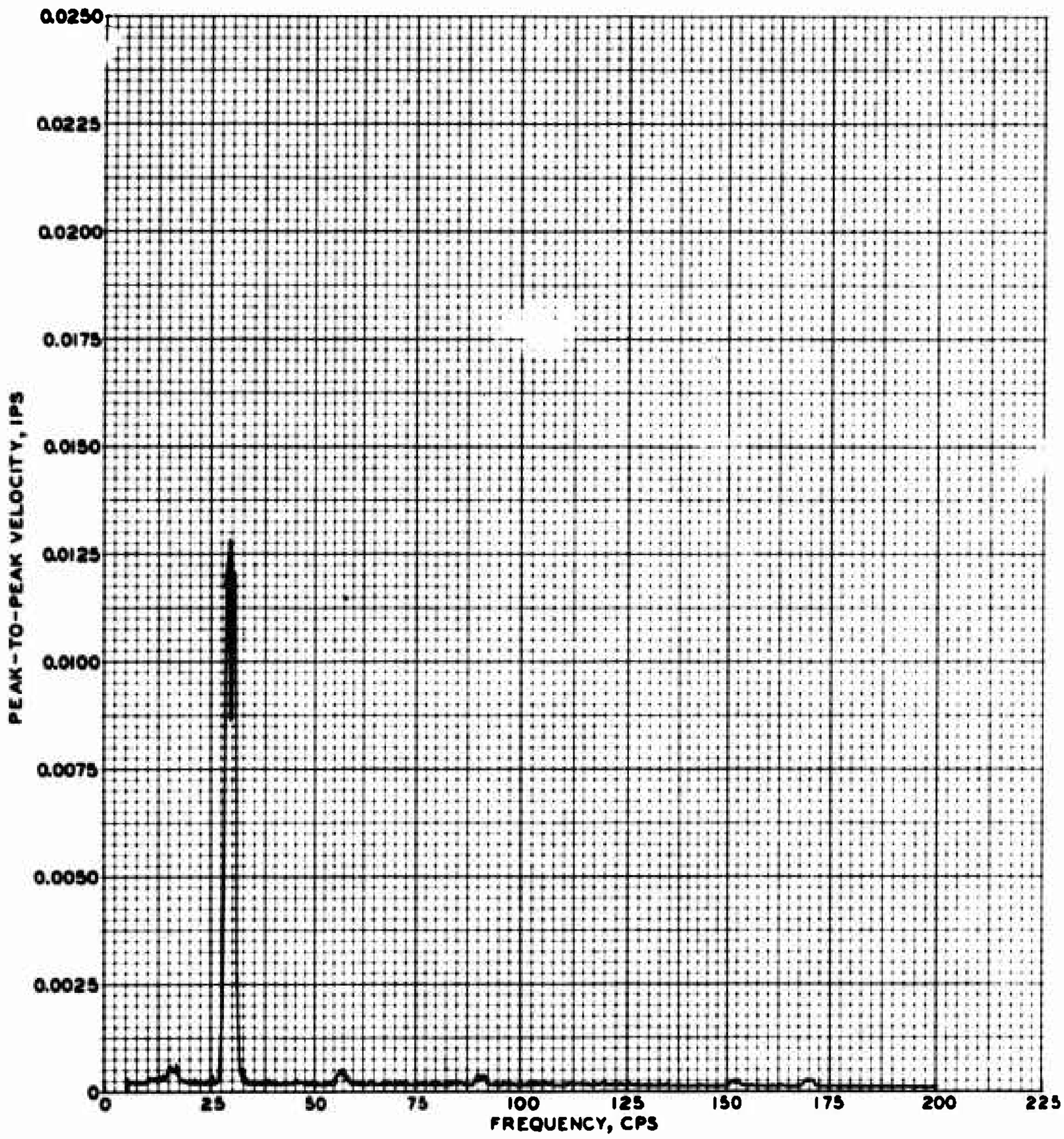
FREQUENCY SPECTRUM ANALYSIS

RUN 26

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



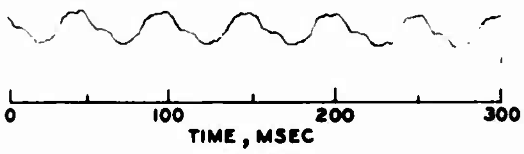
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	30	100

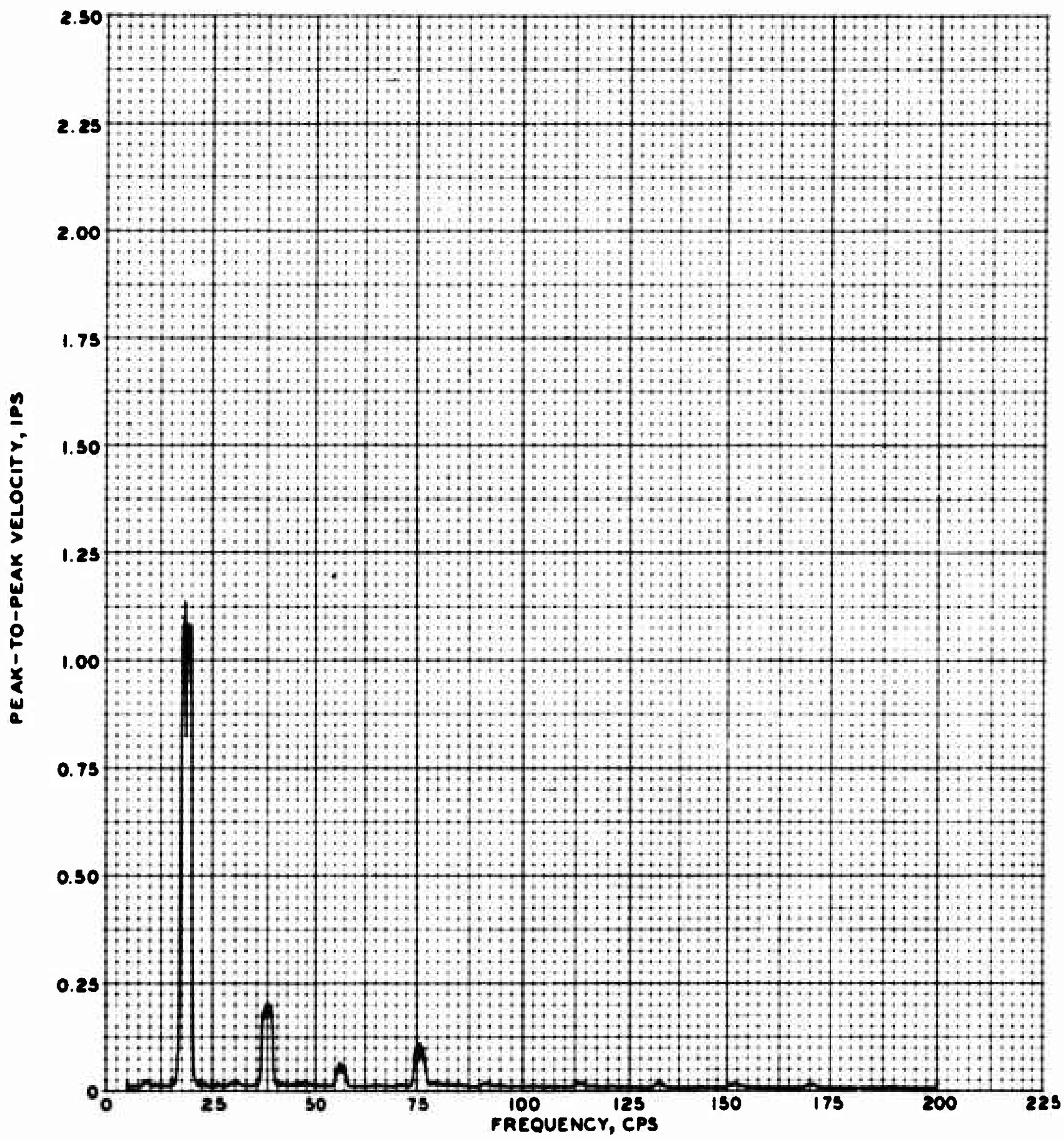
FREQUENCY SPECTRUM ANALYSIS

RUN 26

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



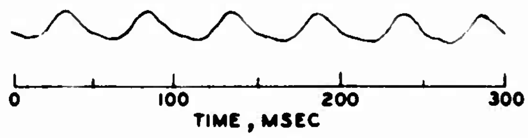
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	20	5840
HYDRAULIC	40	3266
ELECTROMAGNETIC	80	100

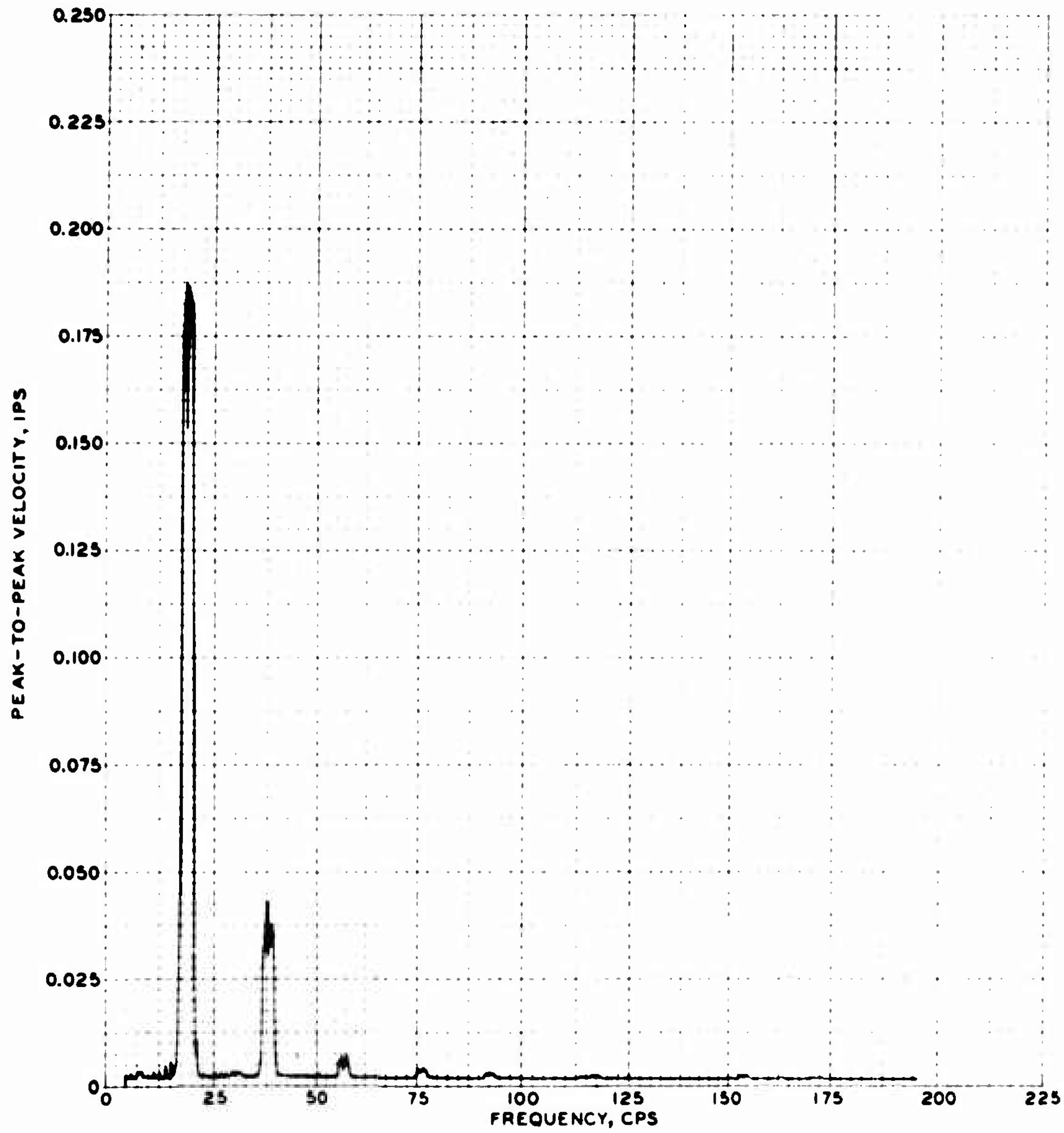
FREQUENCY SPECTRUM ANALYSIS

RUN 38

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



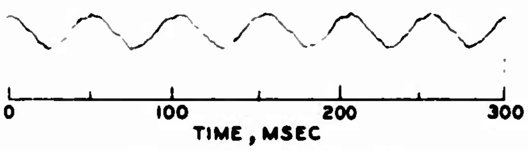
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	20	5840
HYDRAULIC	40	3286
ELECTROMAGNETIC	80	100

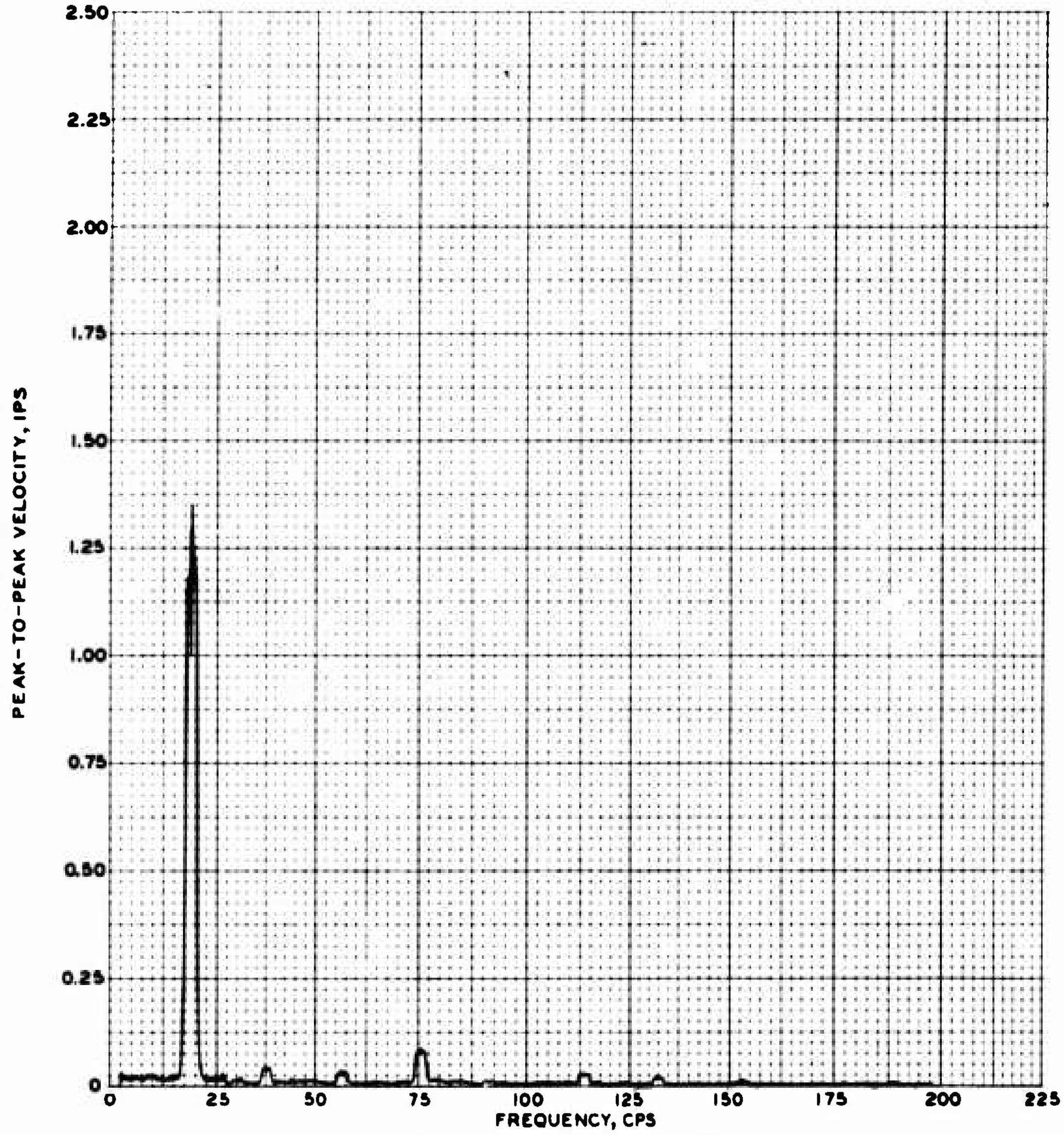
FREQUENCY SPECTRUM ANALYSIS

RUN 38

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



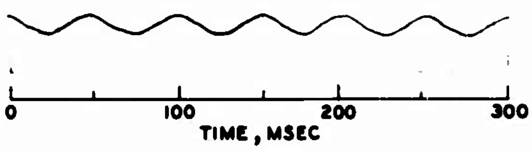
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	20	5840

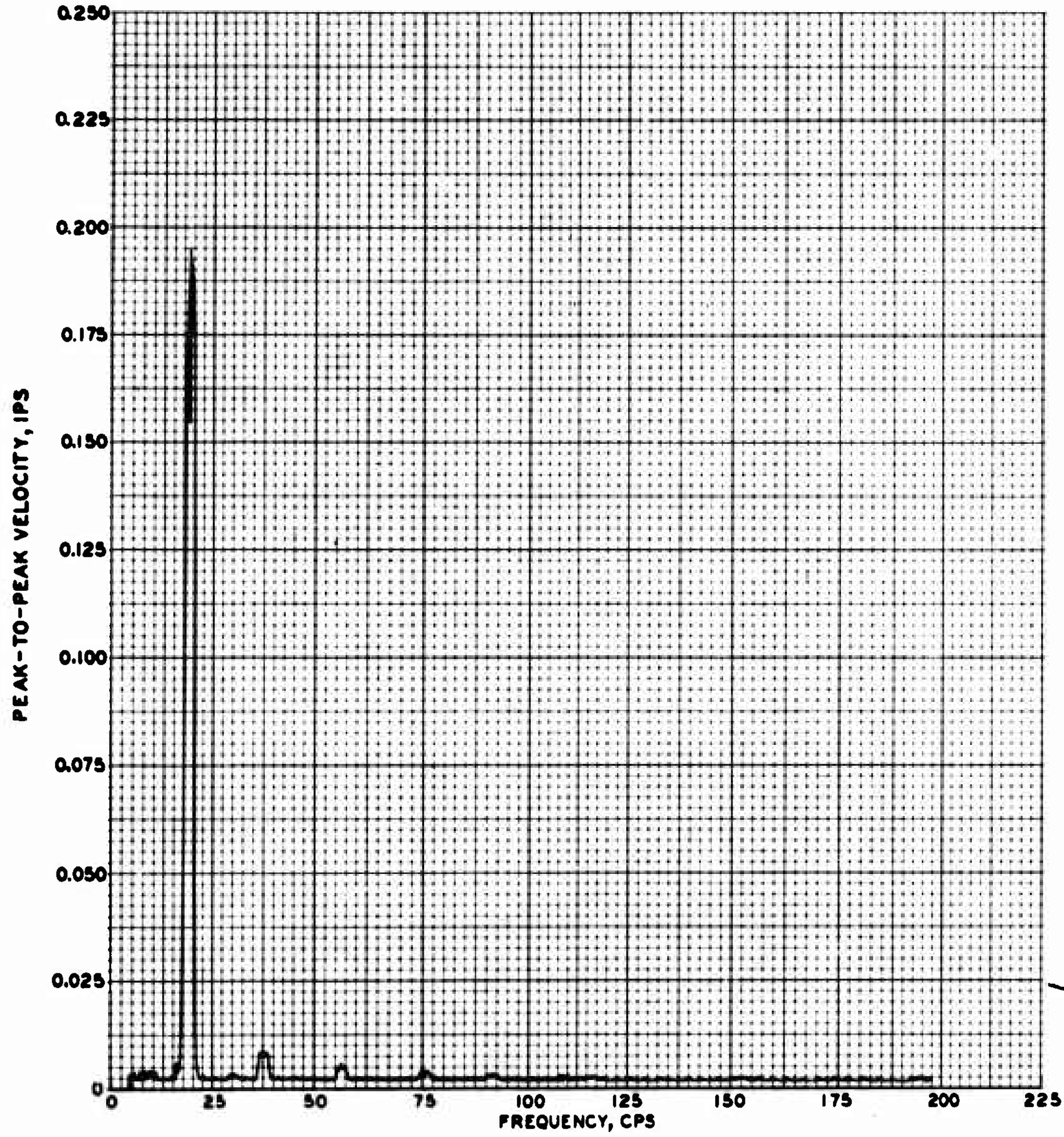
FREQUENCY SPECTRUM ANALYSIS

RUN 4

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



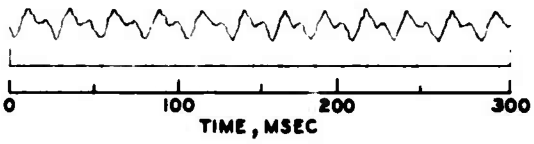
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	20	5840

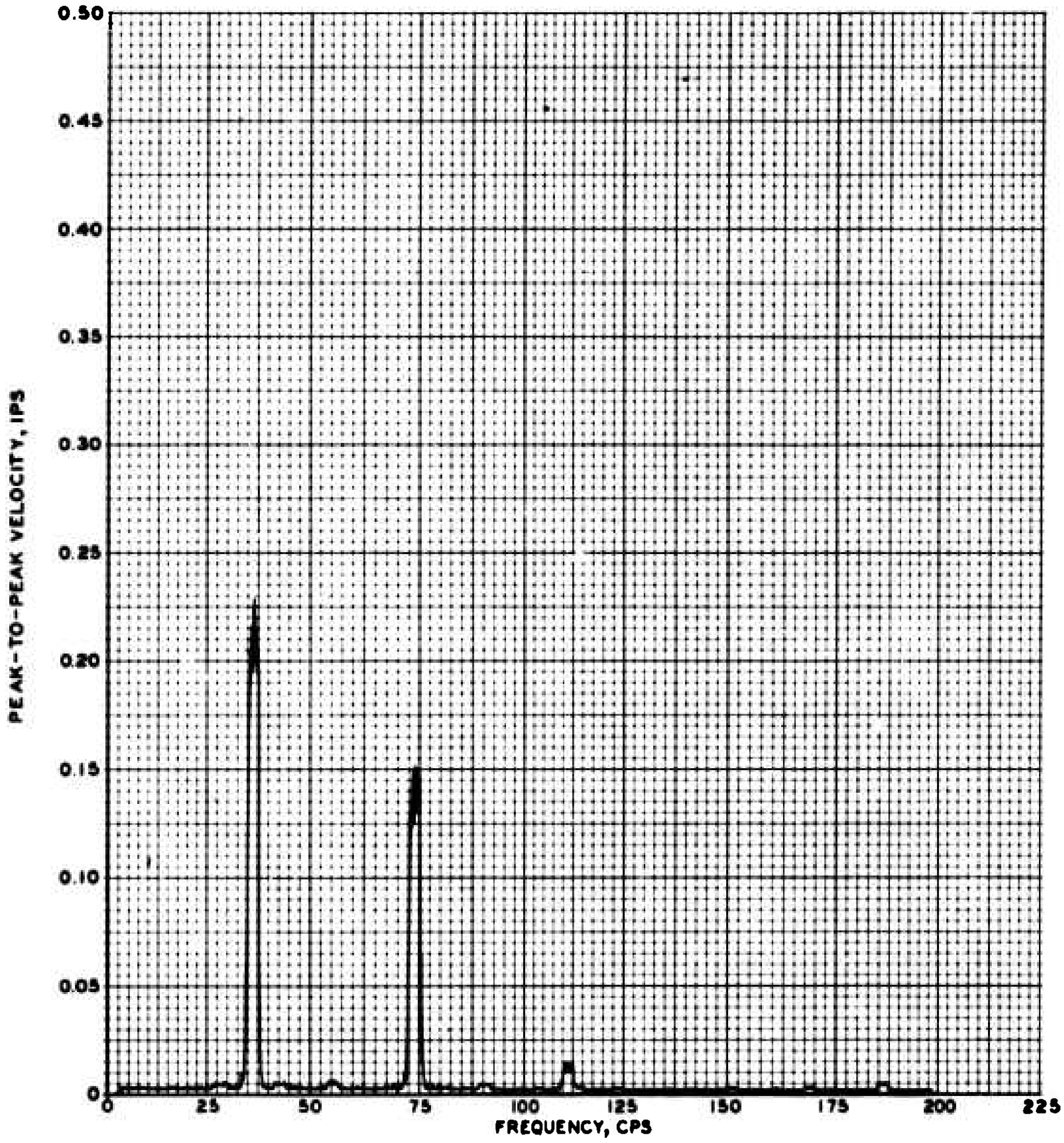
FREQUENCY SPECTRUM ANALYSIS

RUN 4

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



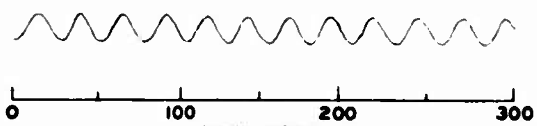
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
HYDRAULIC	40	3266

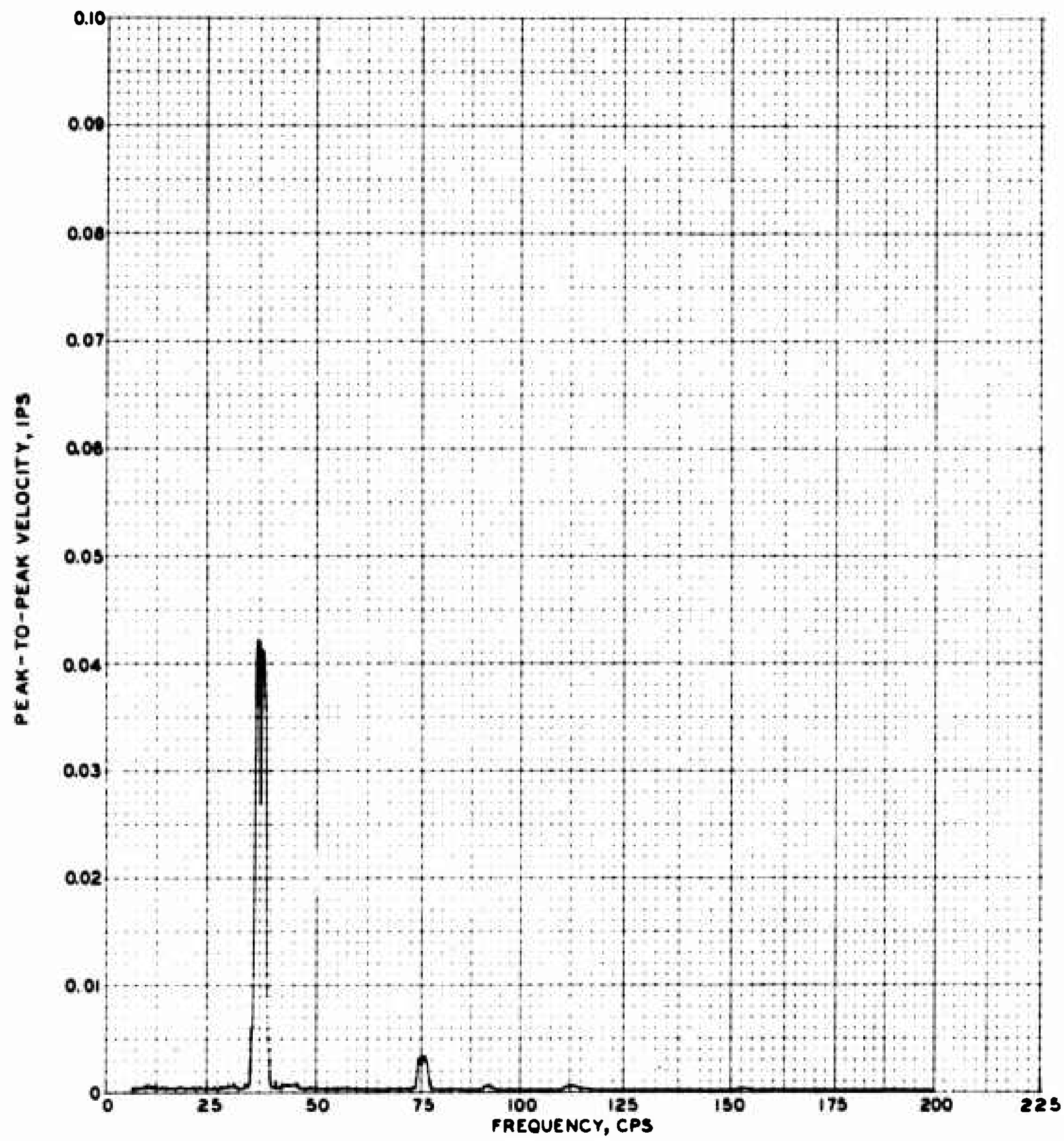
FREQUENCY SPECTRUM ANALYSIS

RUN 24

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



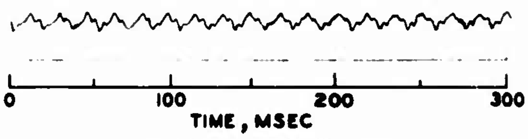
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
HYDRAULIC	40	3266

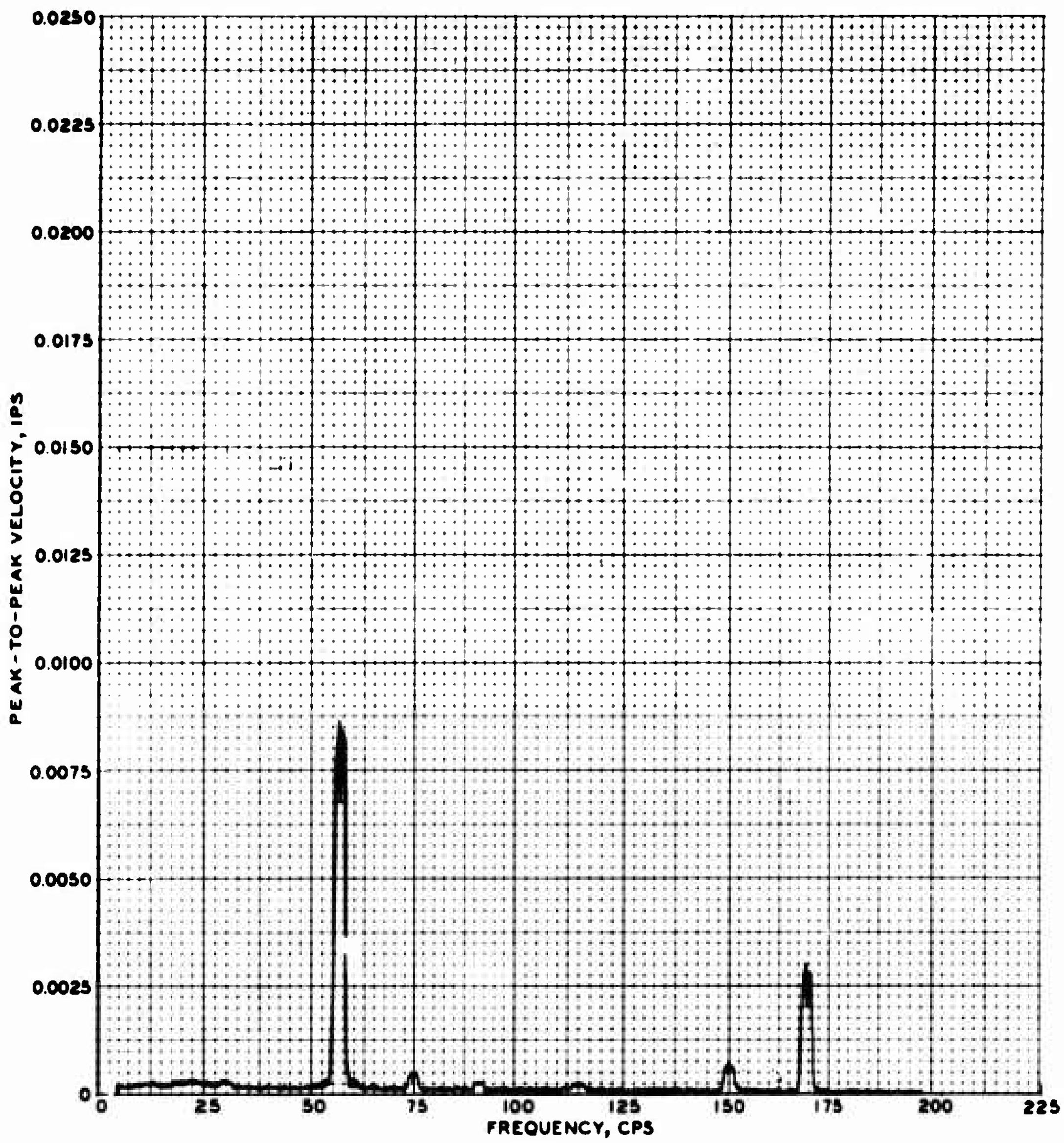
FREQUENCY SPECTRUM ANALYSIS

RUN 24

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



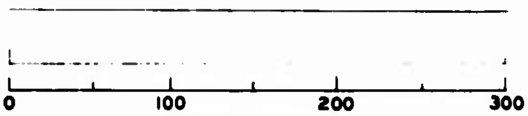
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	80	100

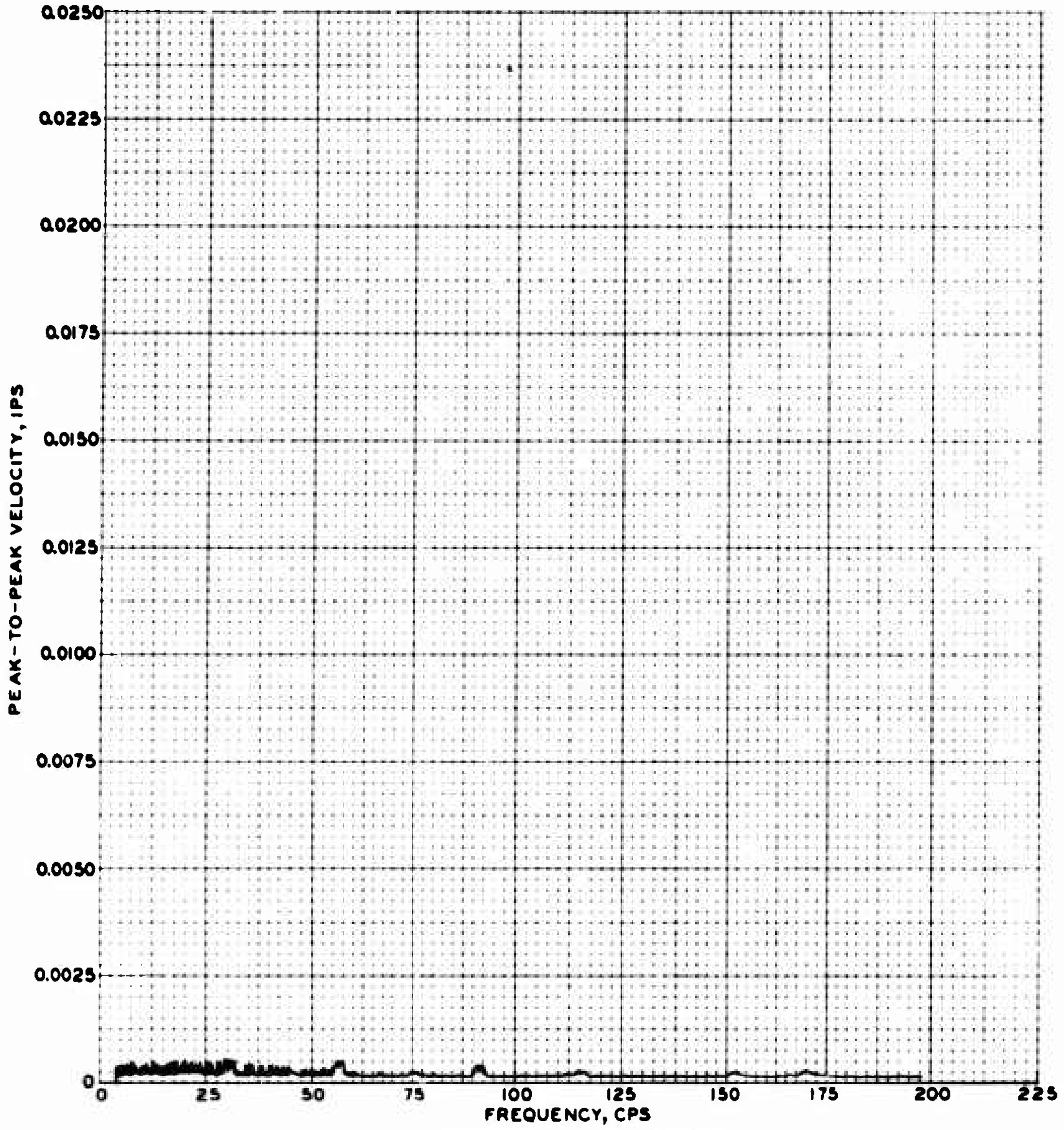
FREQUENCY SPECTRUM ANALYSIS

RUN 31

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



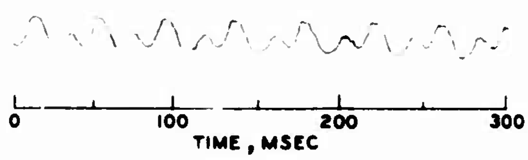
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	80	100

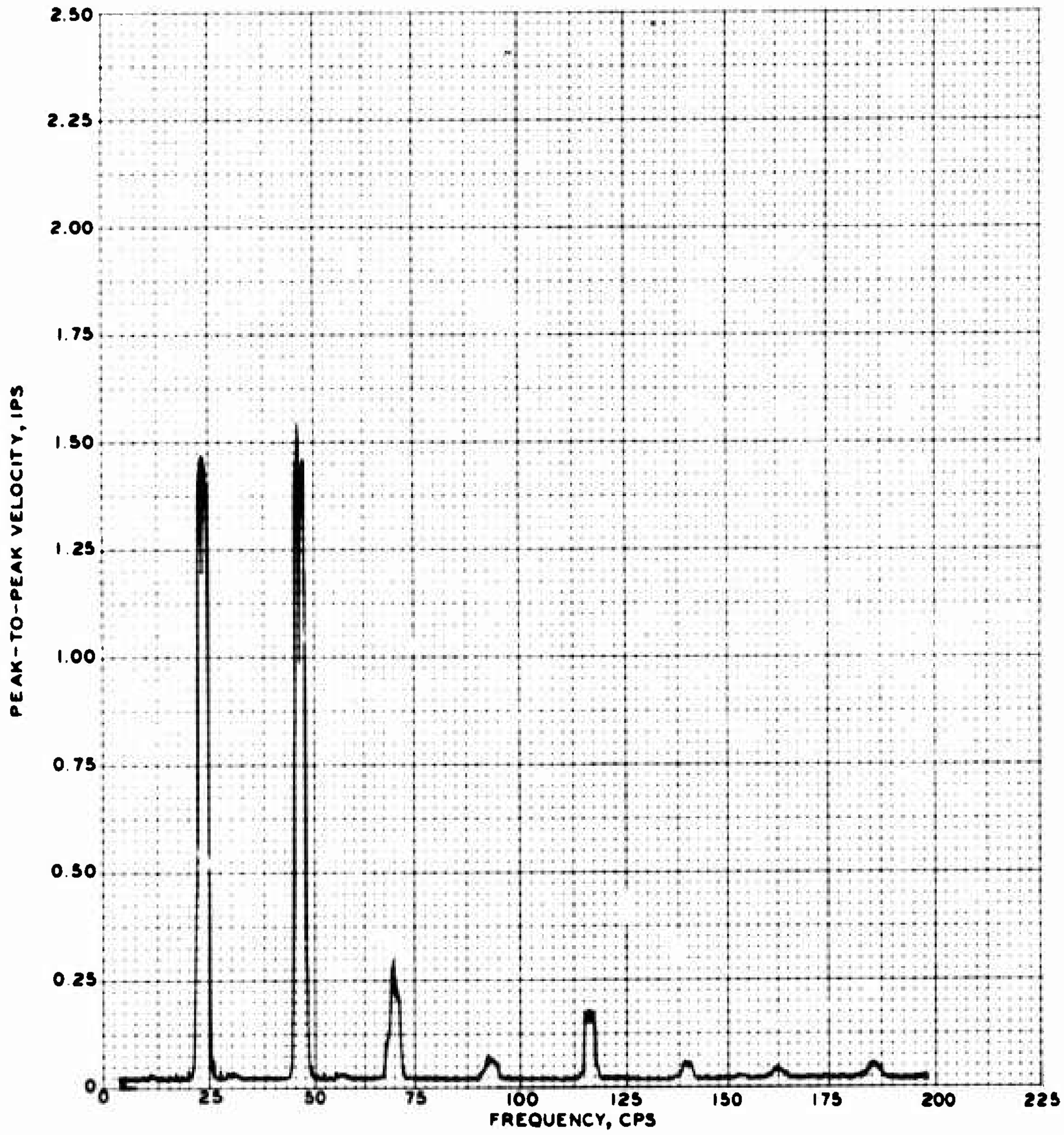
FREQUENCY SPECTRUM ANALYSIS

RUN 31

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



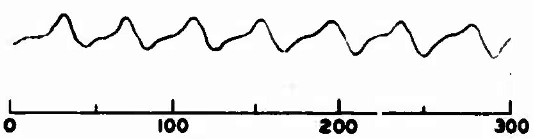
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	25	9125
HYDRAULIC	50	5090
ELECTROMAGNETIC	100	[illegible]

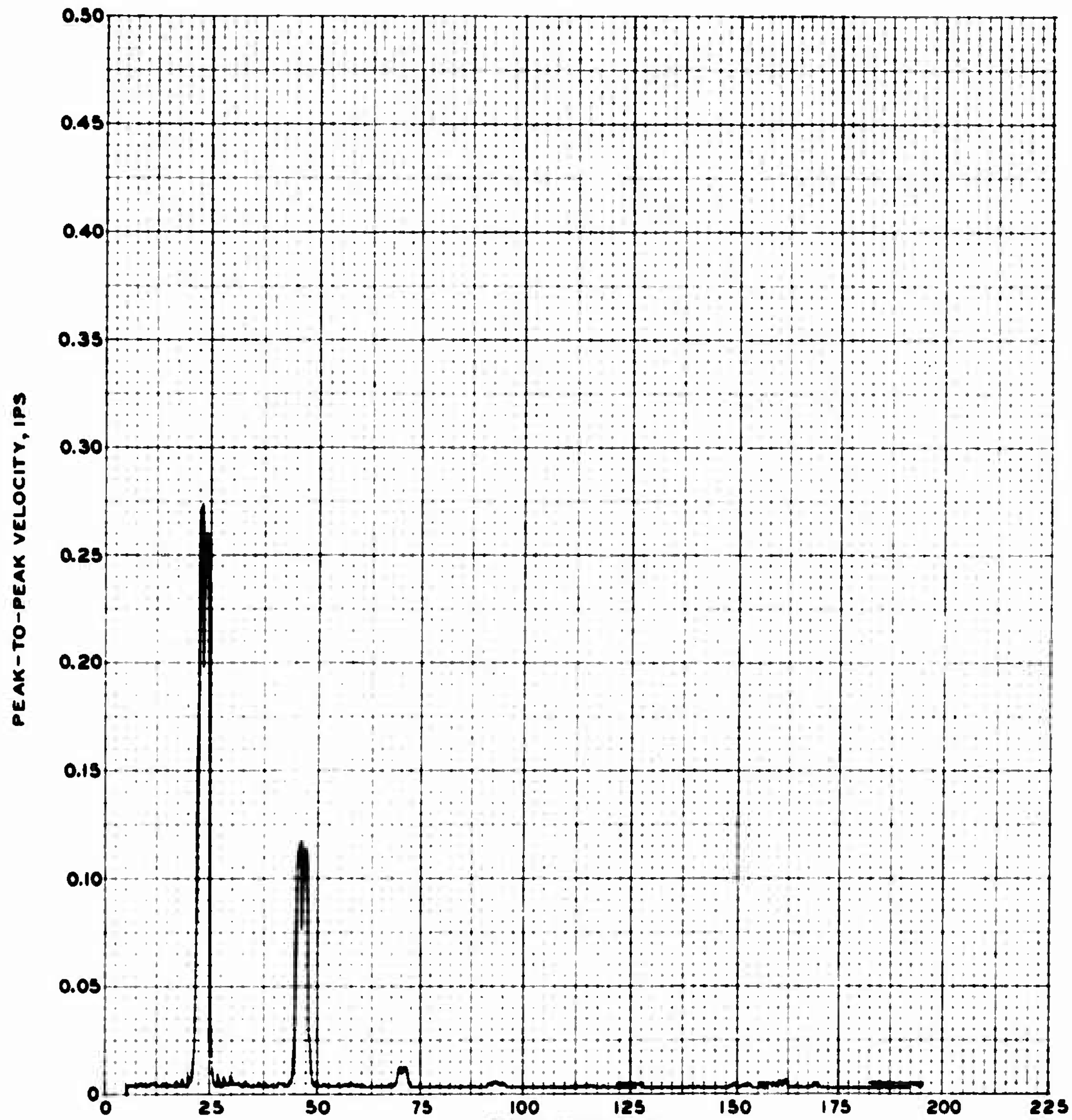
FREQUENCY SPECTRUM ANALYSIS

RUN 39

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



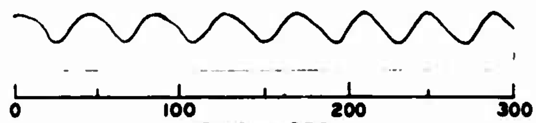
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	25	9125
HYDRAULIC	50	5090
ELECTROMAGNETIC	100	100

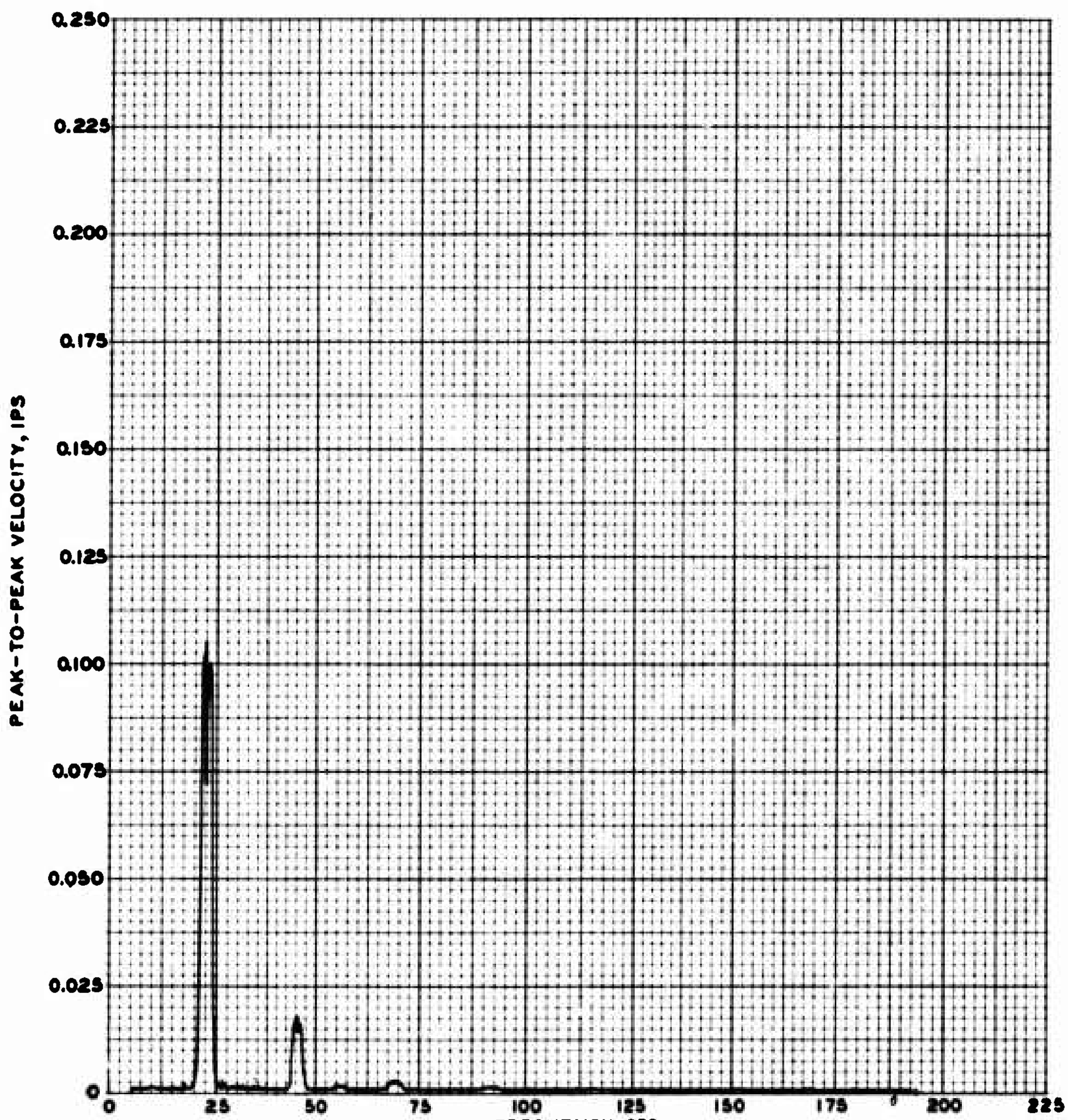
FREQUENCY SPECTRUM ANALYSIS

RUN 39

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



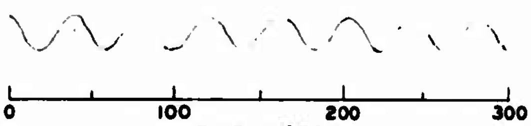
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	25	9125
HYDRAULIC	50	5090
ELECTROMAGNETIC	100	100

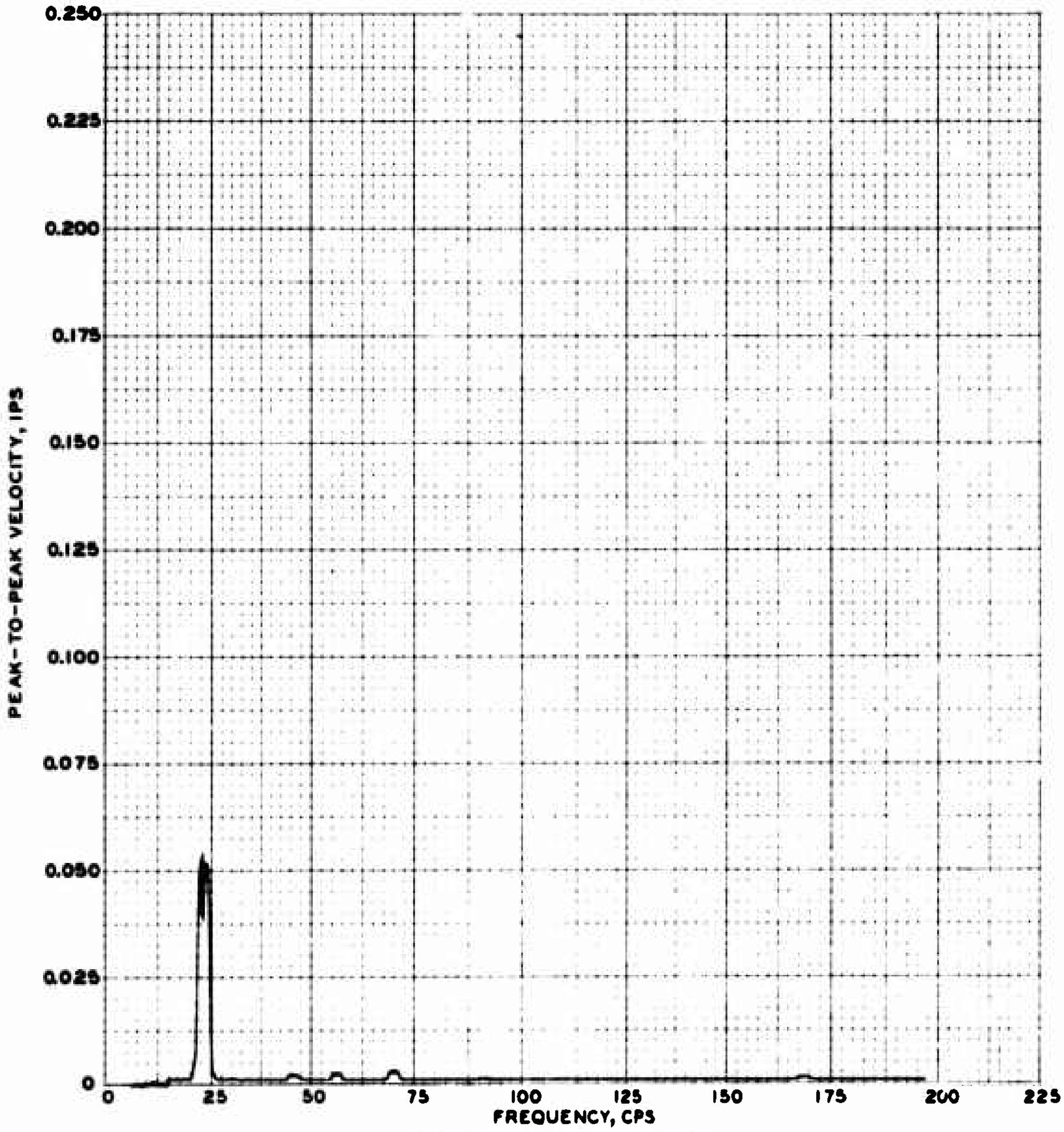
FREQUENCY SPECTRUM ANALYSIS

RUN 39

VERTICAL PICKUP 35 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



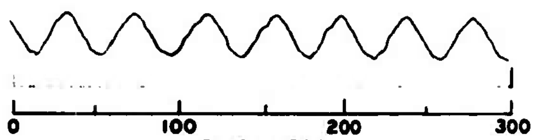
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	25	9125
HYDRAULIC	50	5090
ELECTROMAGNETIC	100	100

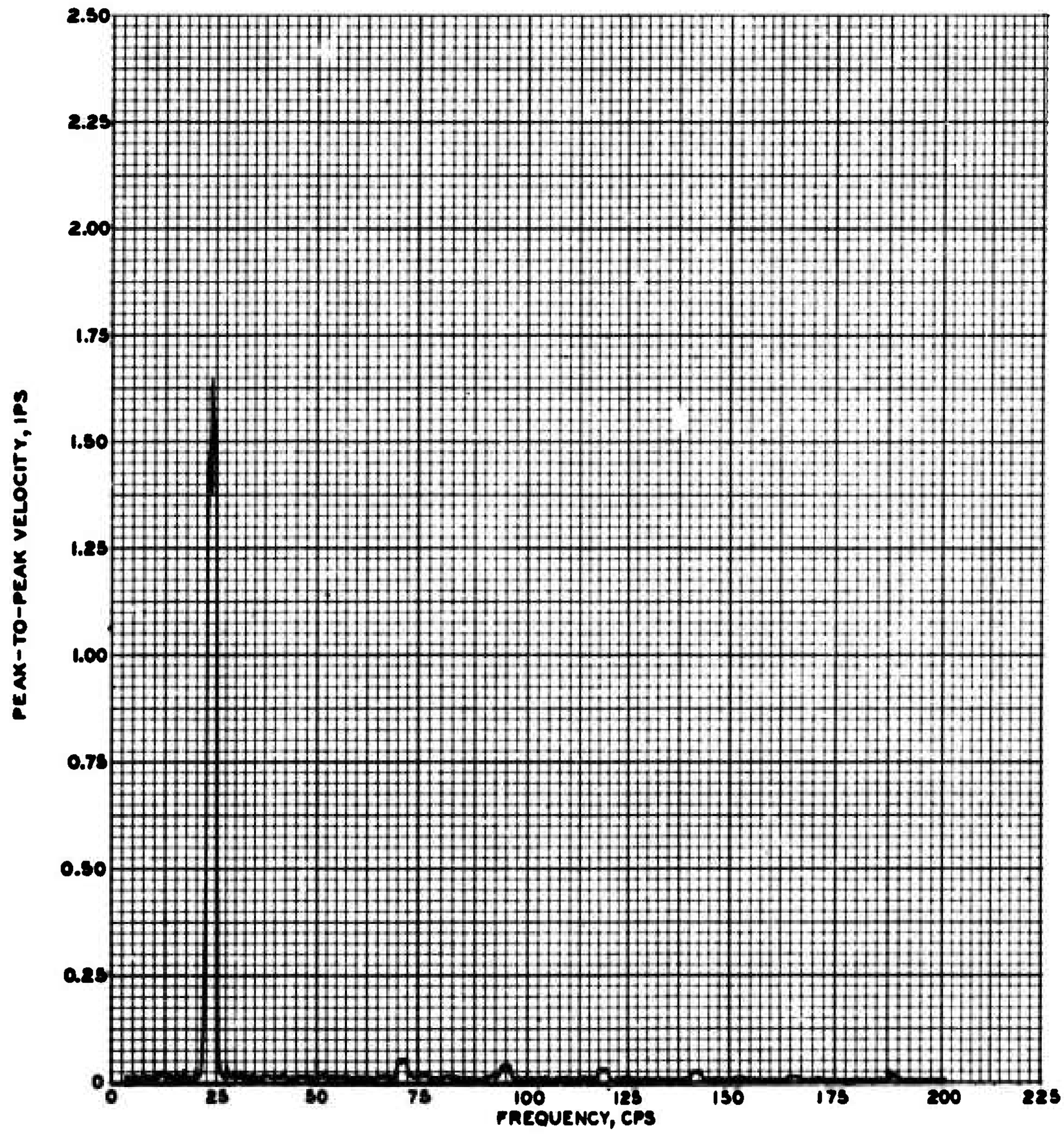
FREQUENCY SPECTRUM ANALYSIS

RUN 39

VERTICAL PICKUP 90 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



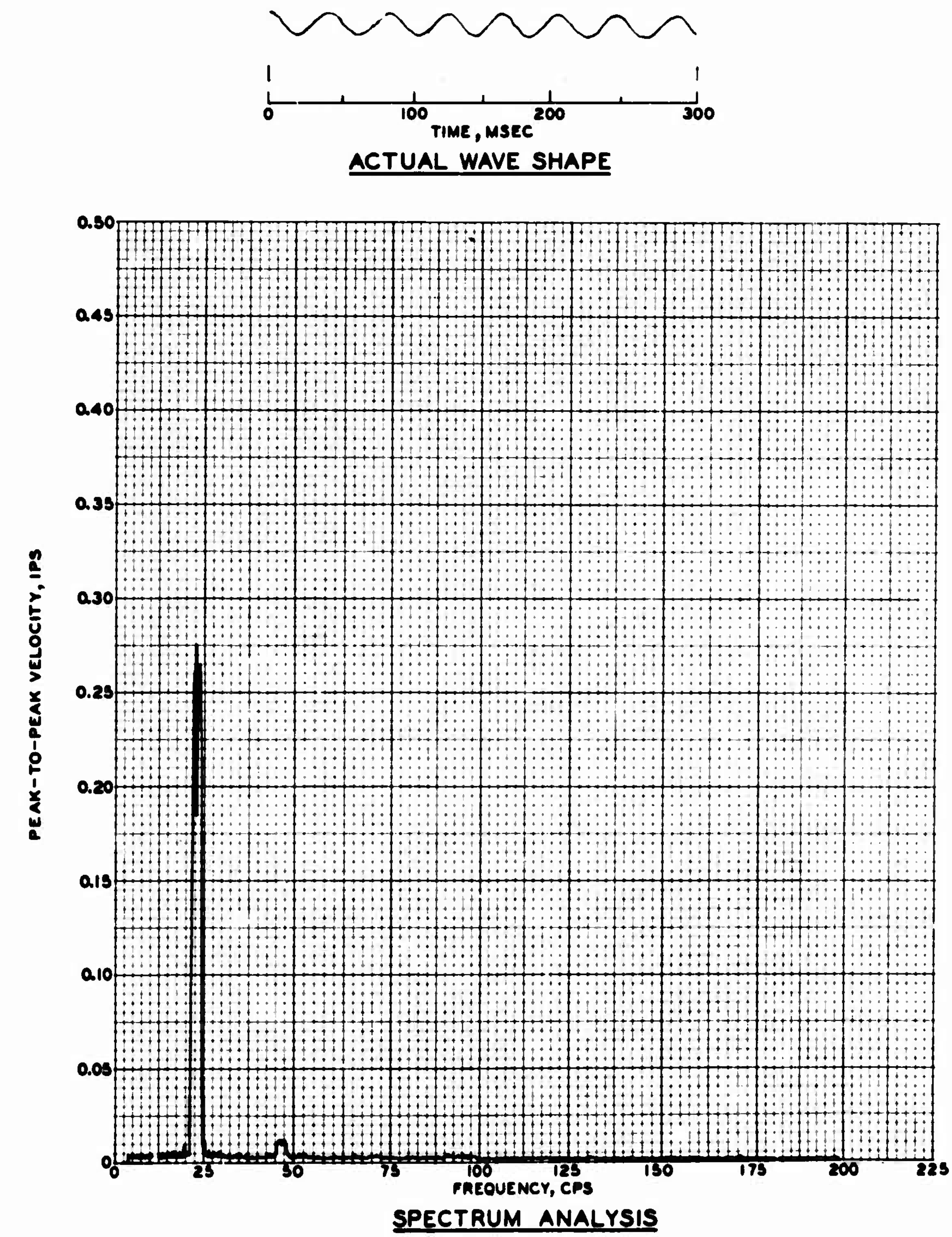
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	25	715

FREQUENCY SPECTRUM ANALYSIS

RUN I

VERTICAL PICKUP ON CONCRETE BASE

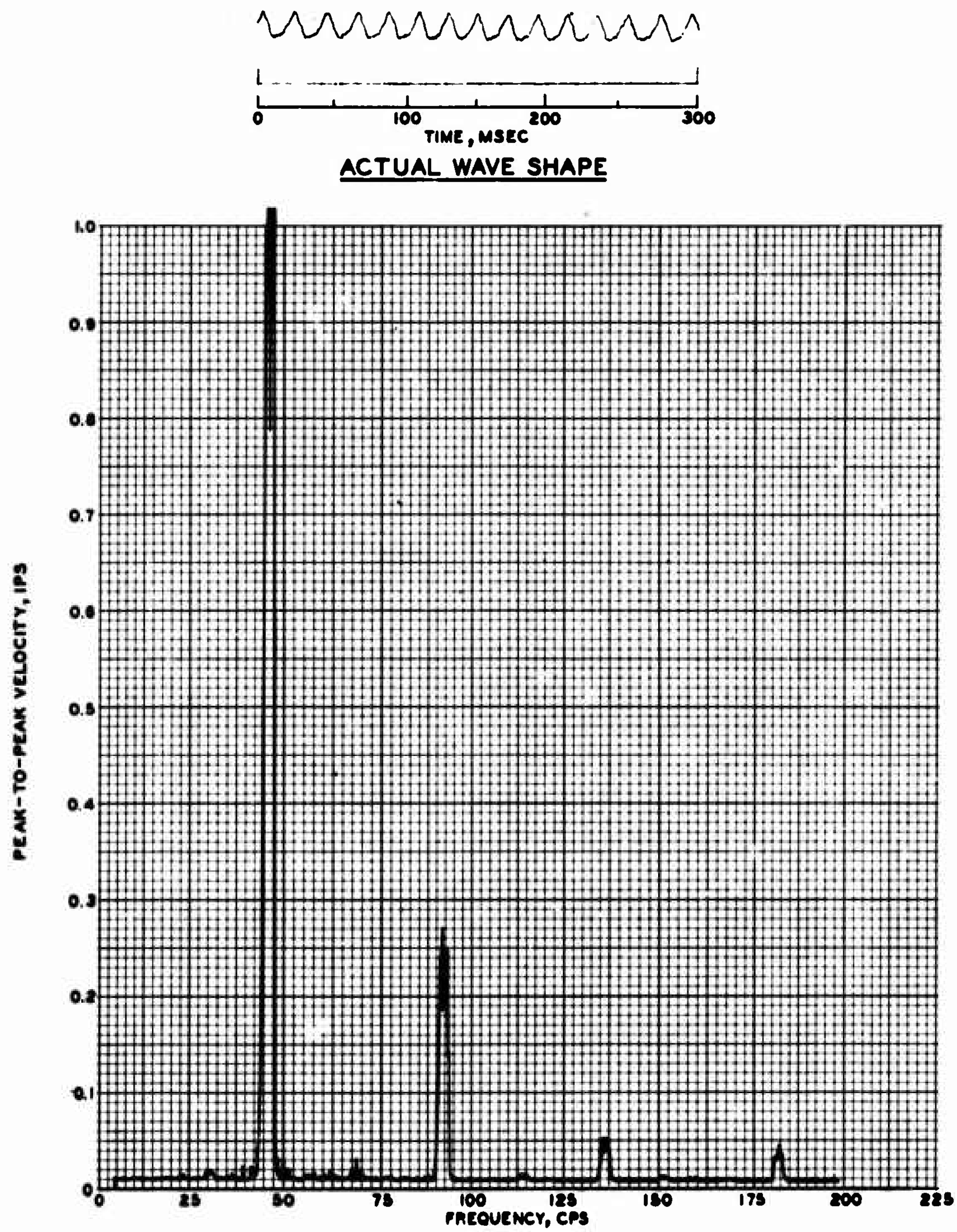


VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
DTMB	25	715

FREQUENCY SPECTRUM ANALYSIS

RUN 1

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



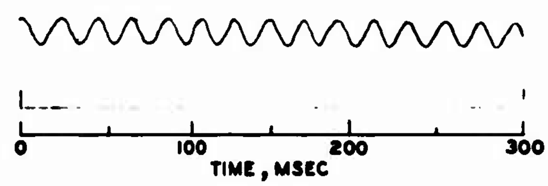
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
HYDRAULIC	50	5090

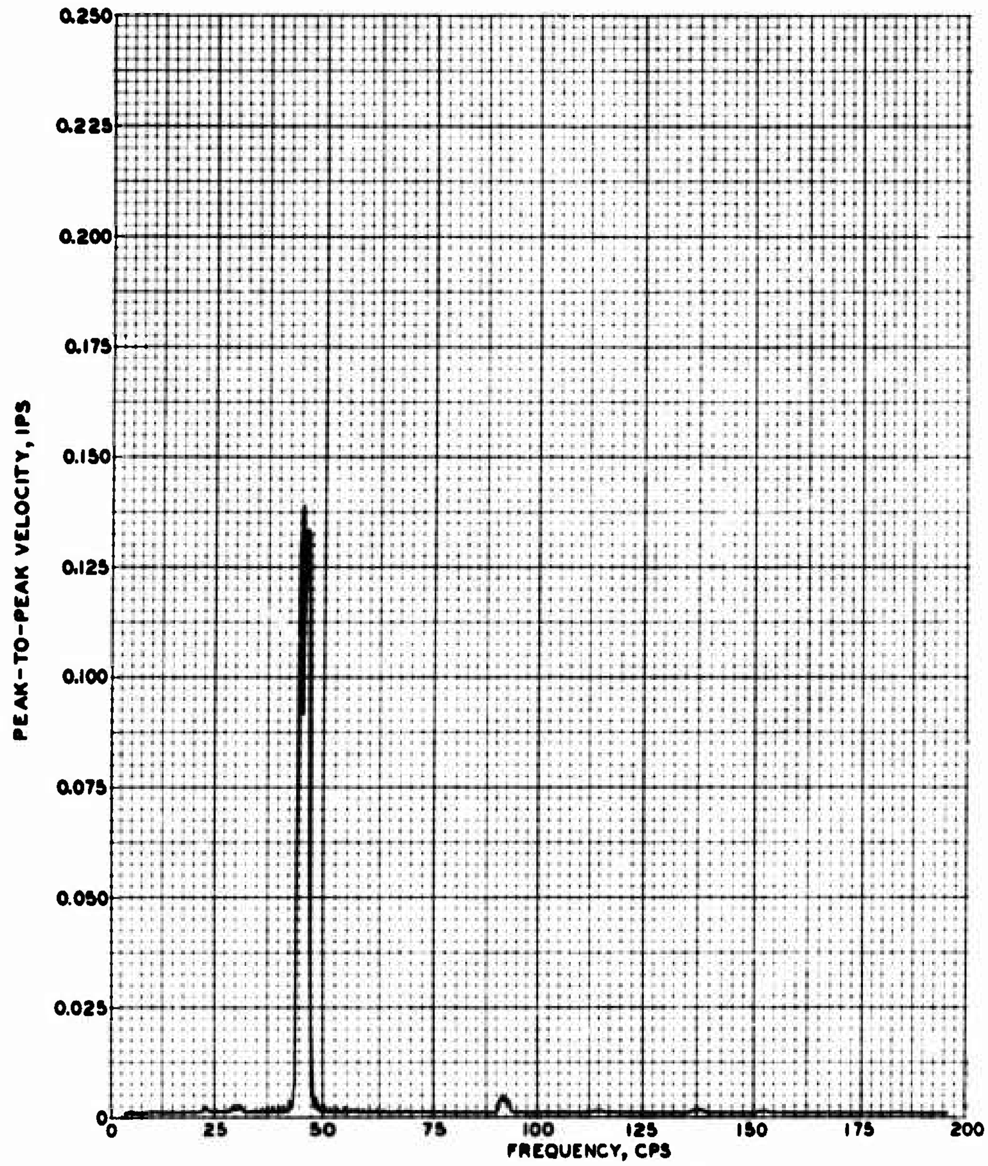
FREQUENCY SPECTRUM ANALYSIS

RUN 25

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



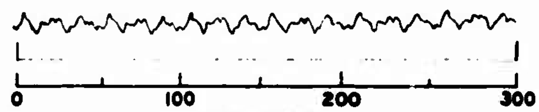
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
HYDRAULIC	50	5090

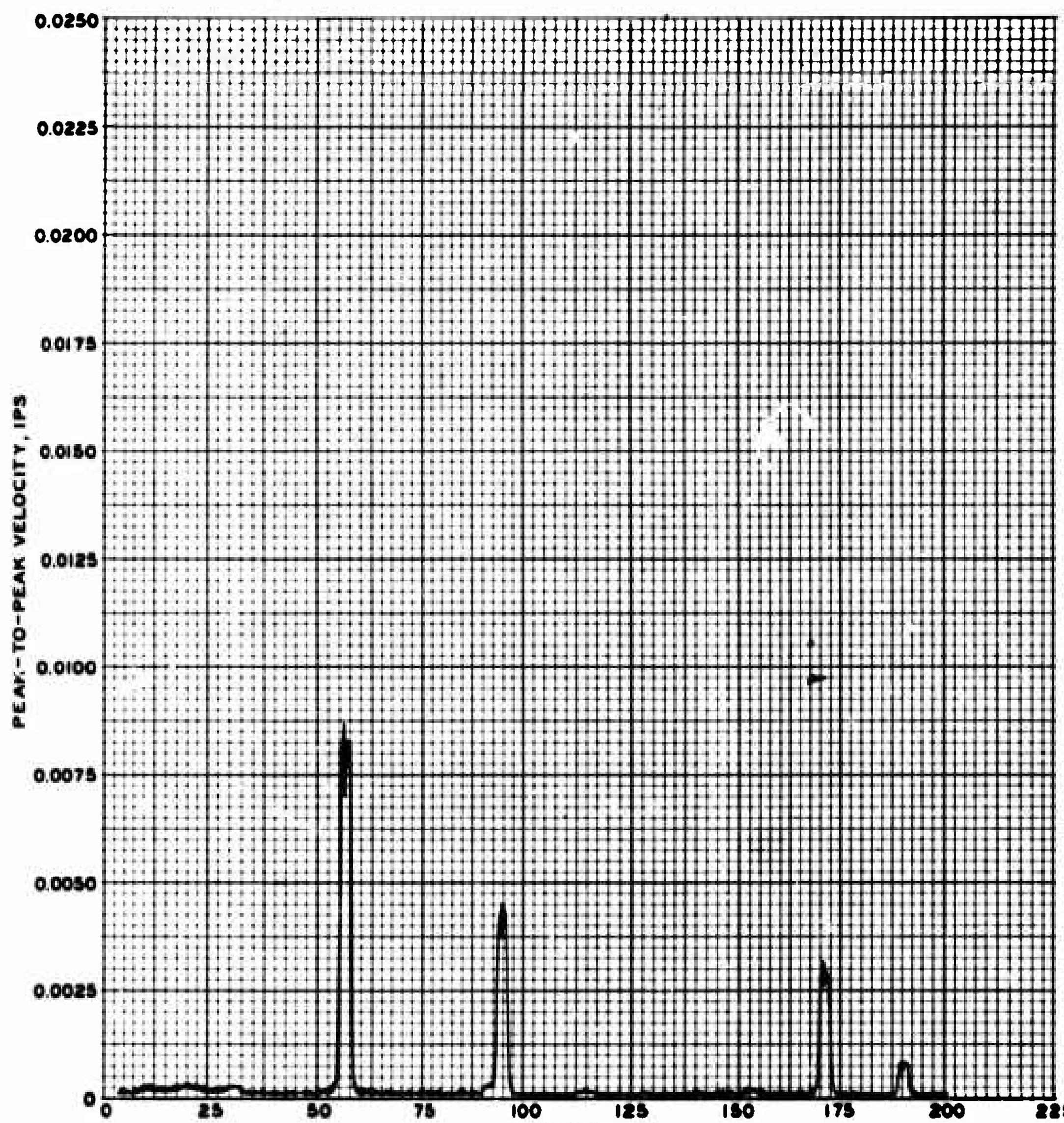
FREQUENCY SPECTRUM ANALYSIS

RUN 25

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



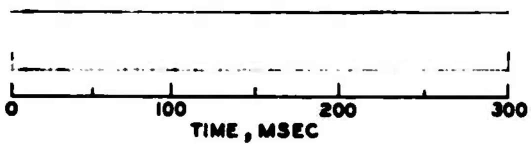
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	100	100

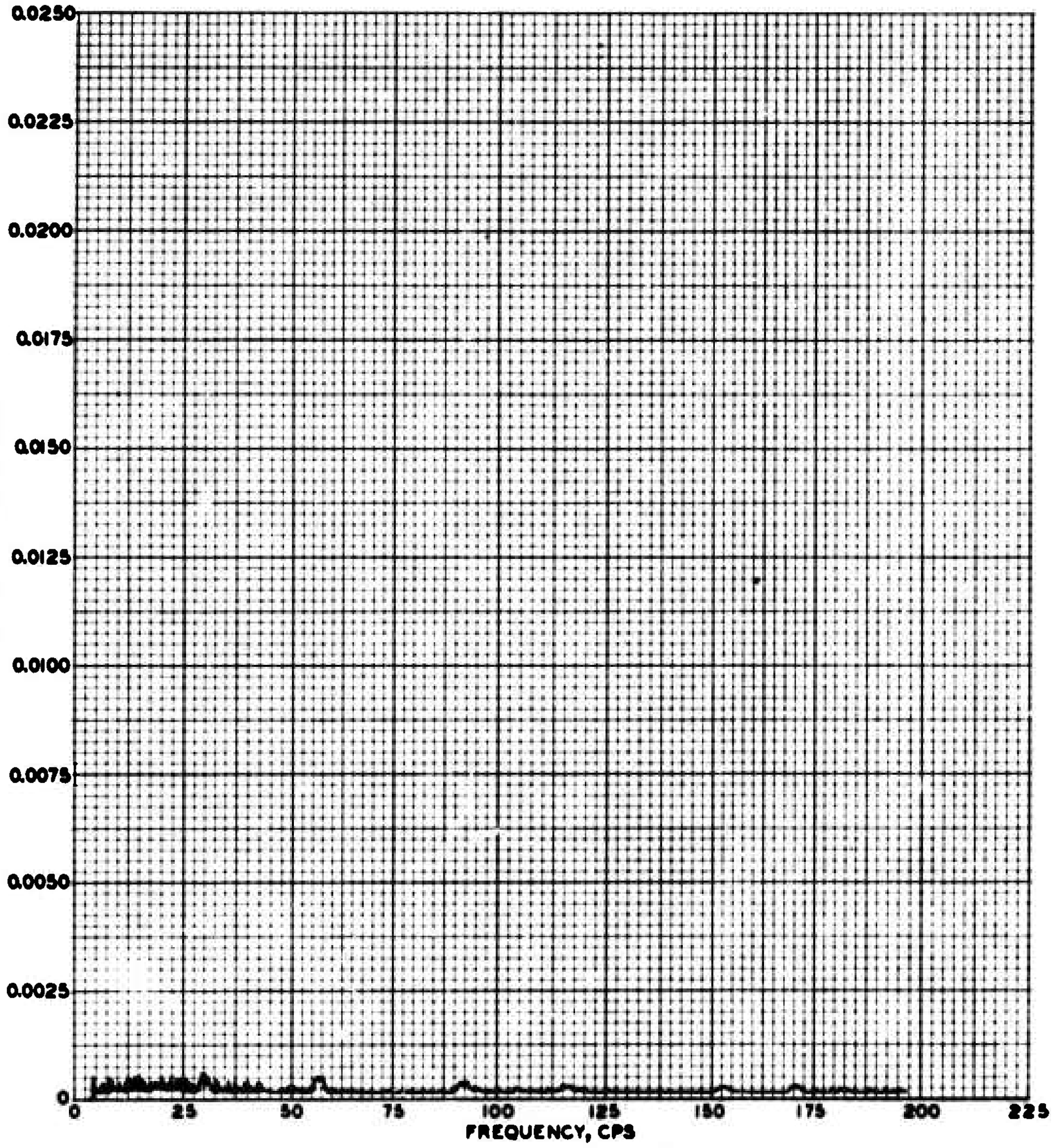
FREQUENCY SPECTRUM ANALYSIS

RUN 33

VERTICAL PICKUP ON CONCRETE BASE



ACTUAL WAVE SHAPE



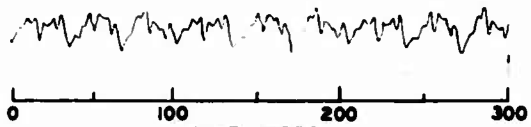
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	100	100

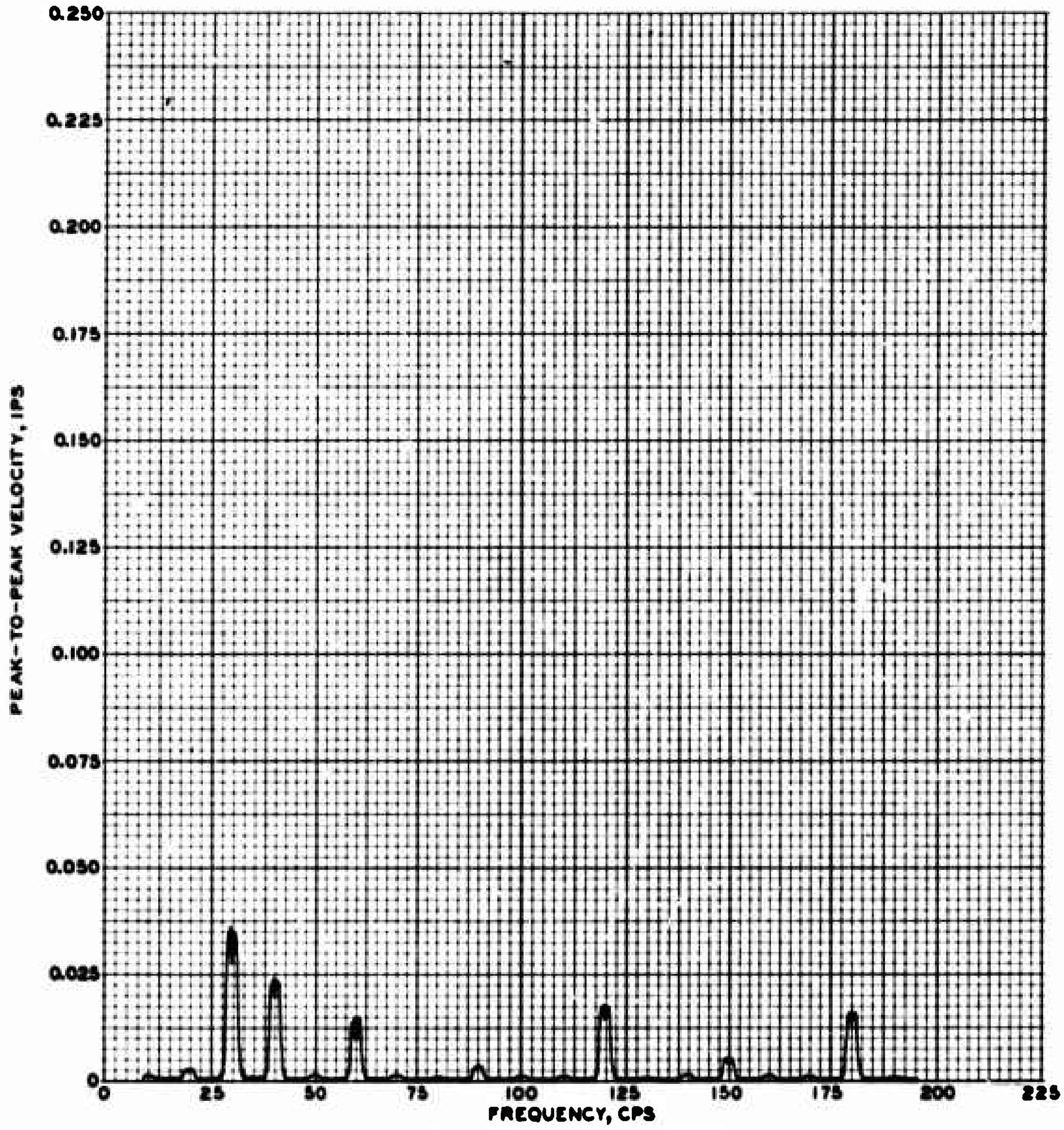
FREQUENCY SPECTRUM ANALYSIS

RUN 33

VERTICAL PICKUP 15 FT FROM CONCRETE BASE



ACTUAL WAVE SHAPE



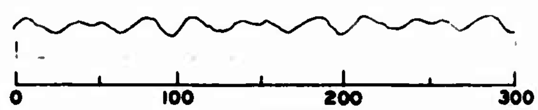
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	30,40	50,50

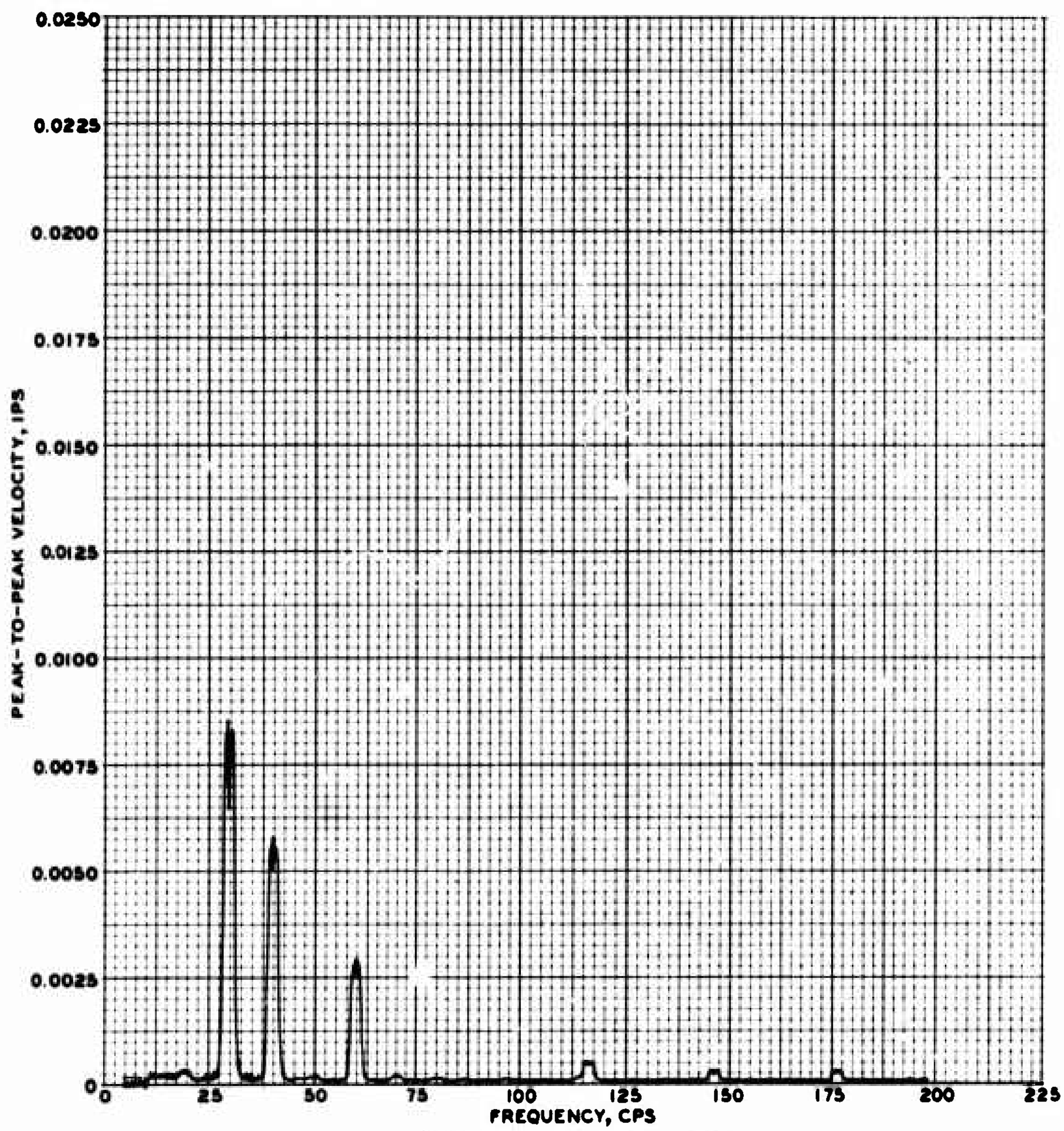
FREQUENCY SPECTRUM ANALYSIS

RUN 59

VERTICAL PICKUP 3 FT FROM VIBRATORS



ACTUAL WAVE SHAPE



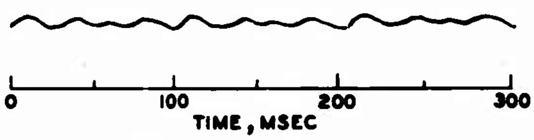
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	30,40	50,50

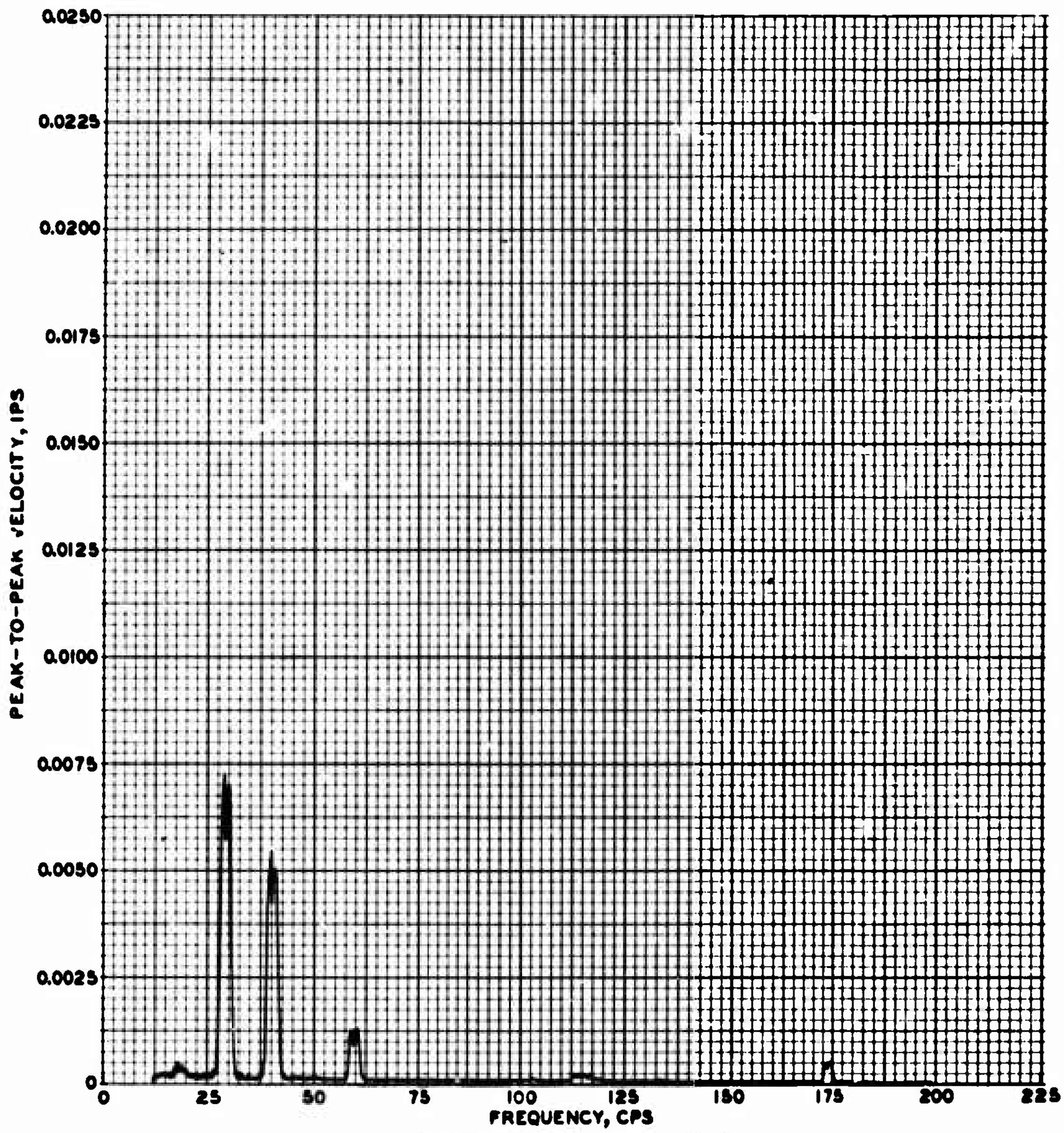
FREQUENCY SPECTRUM ANALYSIS

RUN 59

VERTICAL PICKUP 13 FT FROM VIBRATORS



ACTUAL WAVE SHAPE



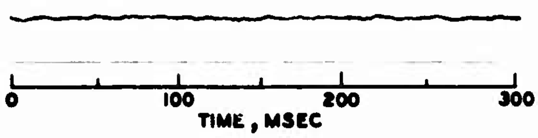
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	30,40	50,50

FREQUENCY SPECTRUM ANALYSIS

RUN 59

VERTICAL PICKUP 33 FT FROM VIBRATORS



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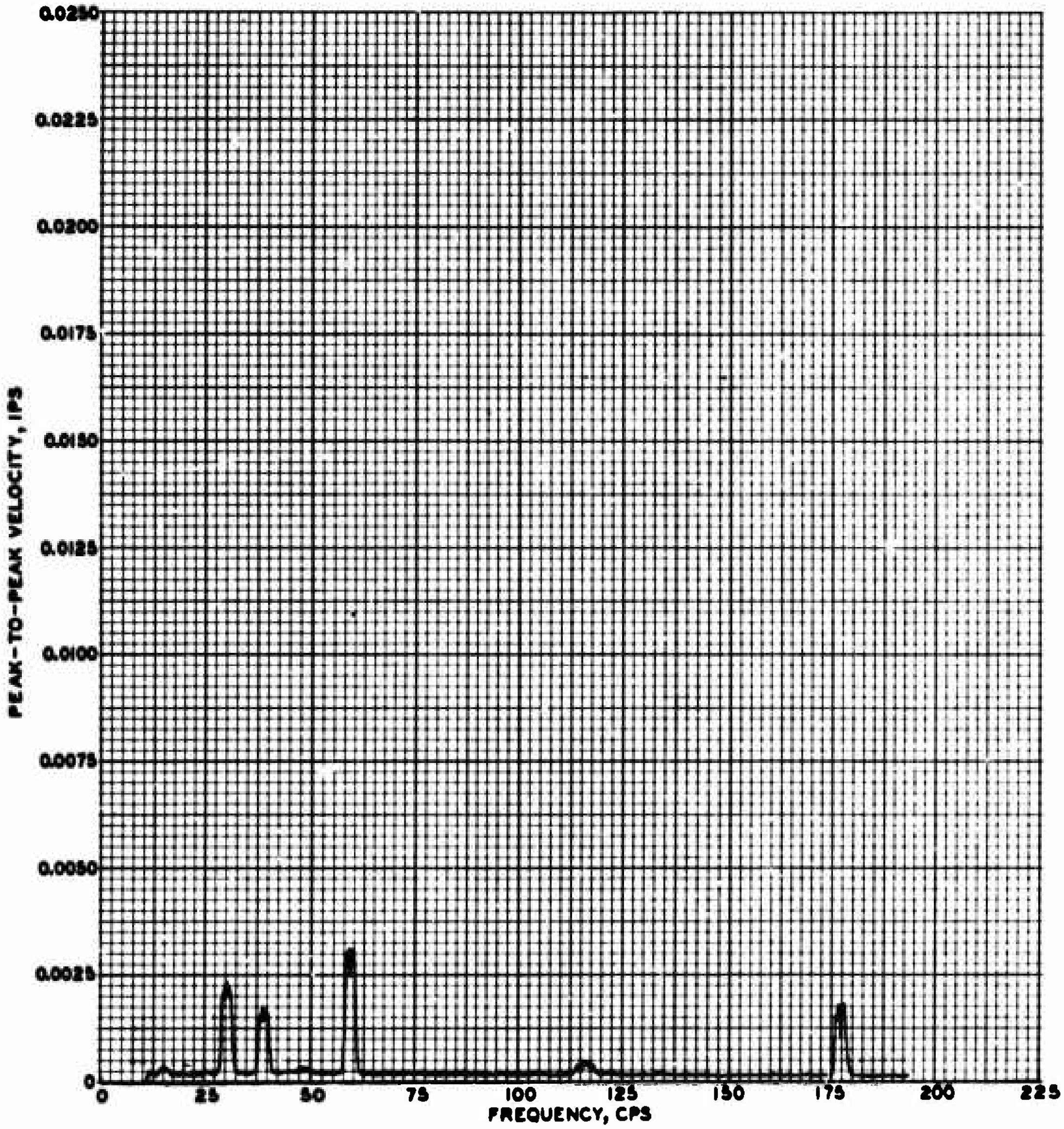


SPECTRUM ANALYSIS

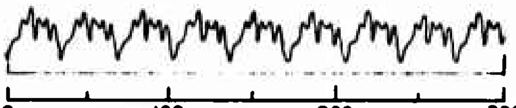
VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	30,40	50,50

FREQUENCY SPECTRUM ANALYSIS

RUN 59

VERTICAL PICKUP 88 FT FROM VIBRATORS

PLATE 48



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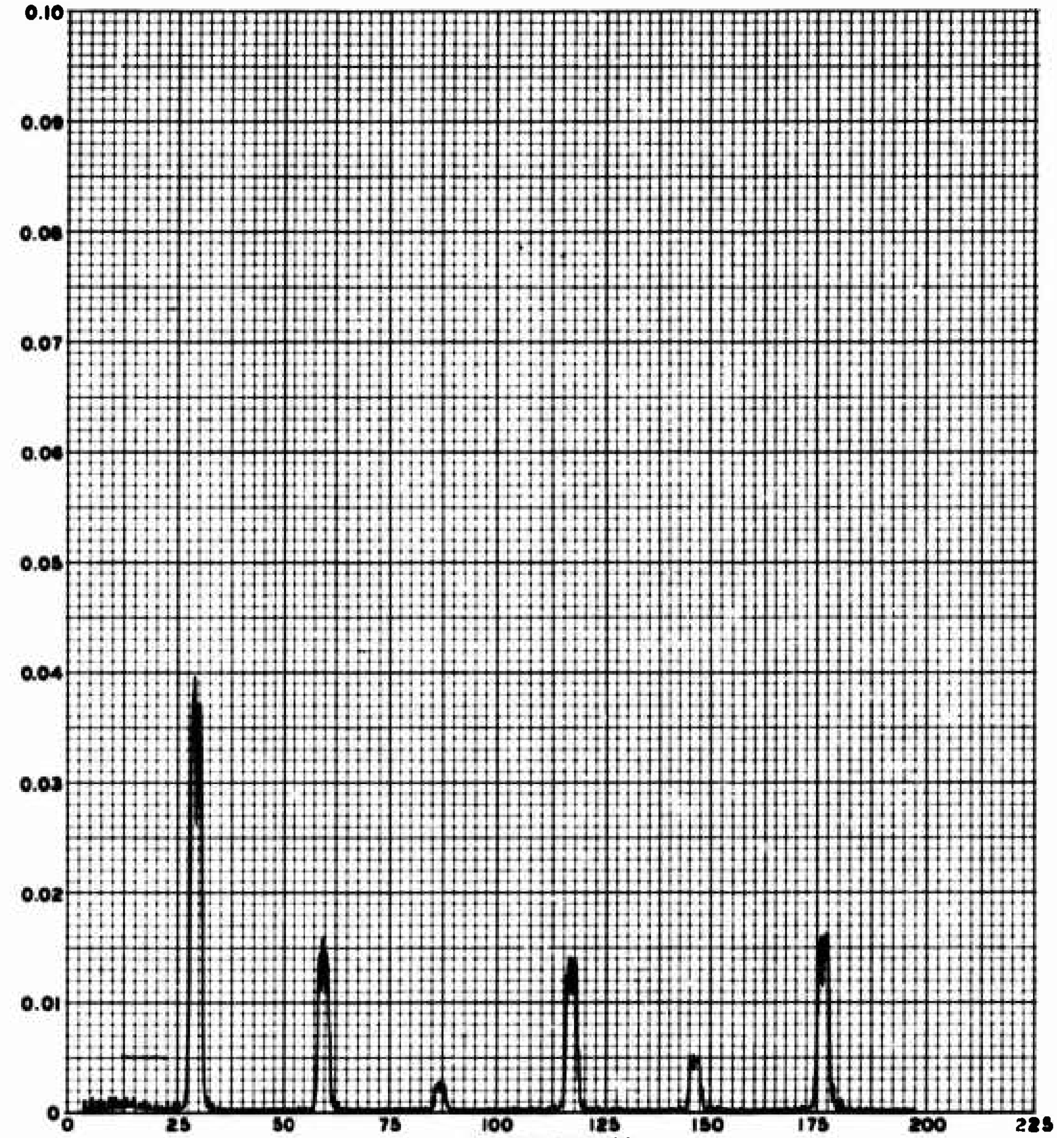


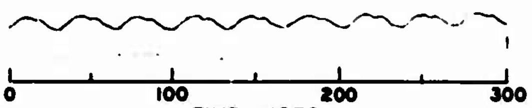
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	30	100

FREQUENCY SPECTRUM ANALYSIS

RUN 57

VERTICAL PICKUP 3 FT FROM VIBRATOR



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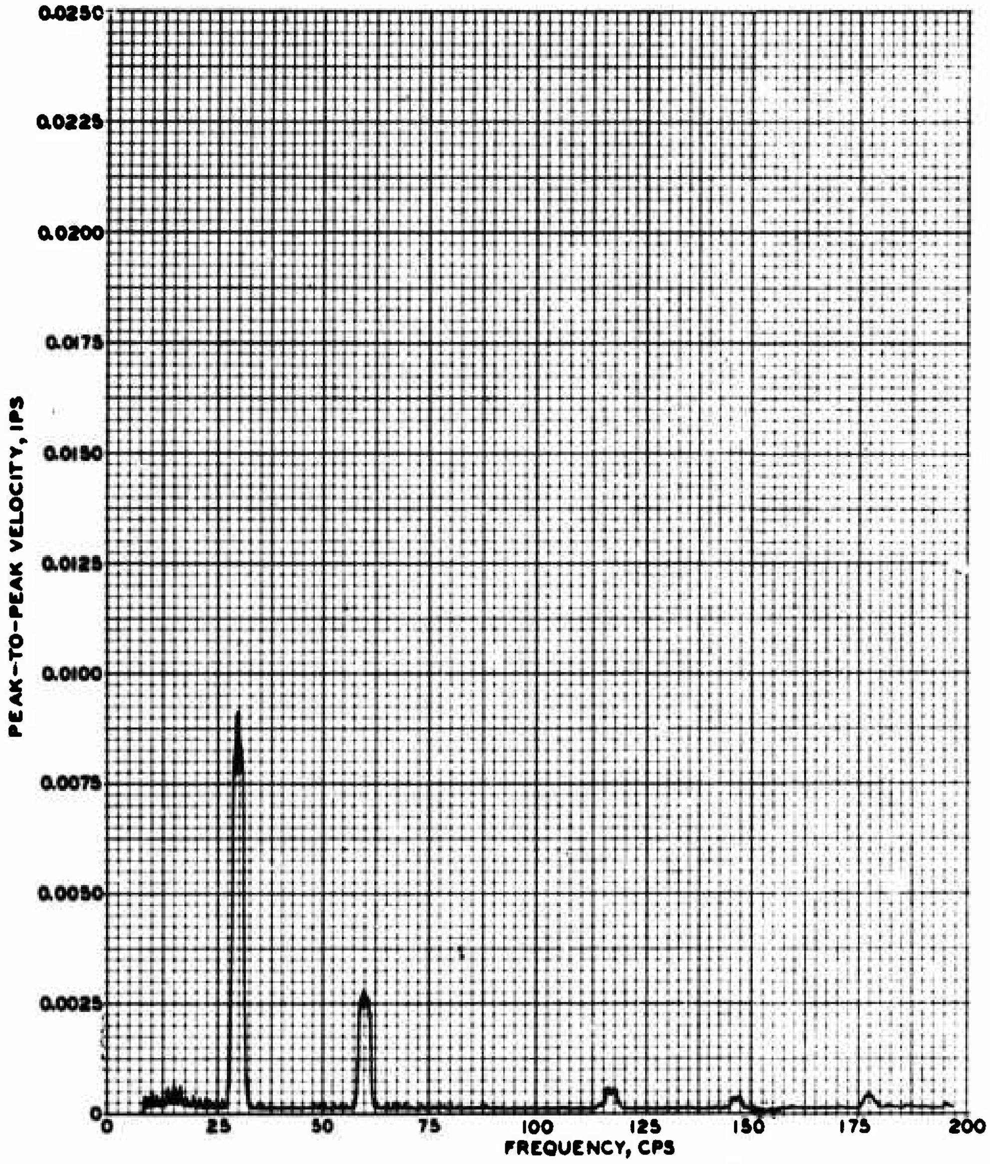


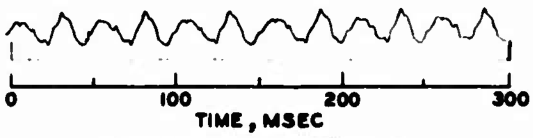
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	30	100

FREQUENCY SPECTRUM ANALYSIS

RUN 57

VERTICAL PICKUP 13 FT FROM VIBRATOR



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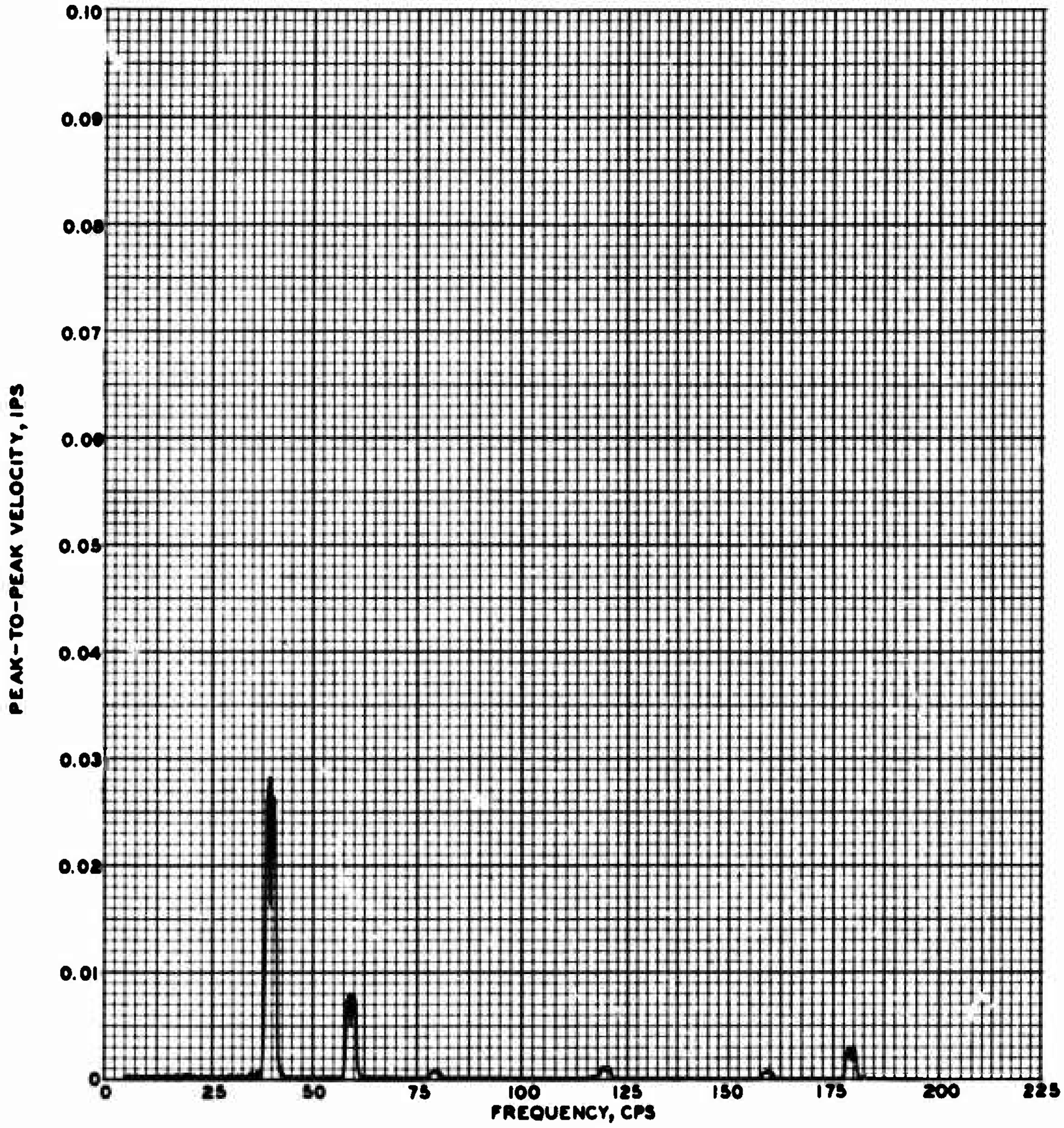


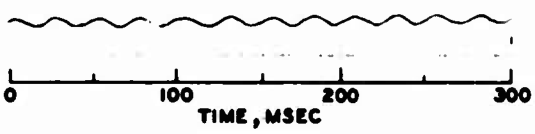
SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	40	100

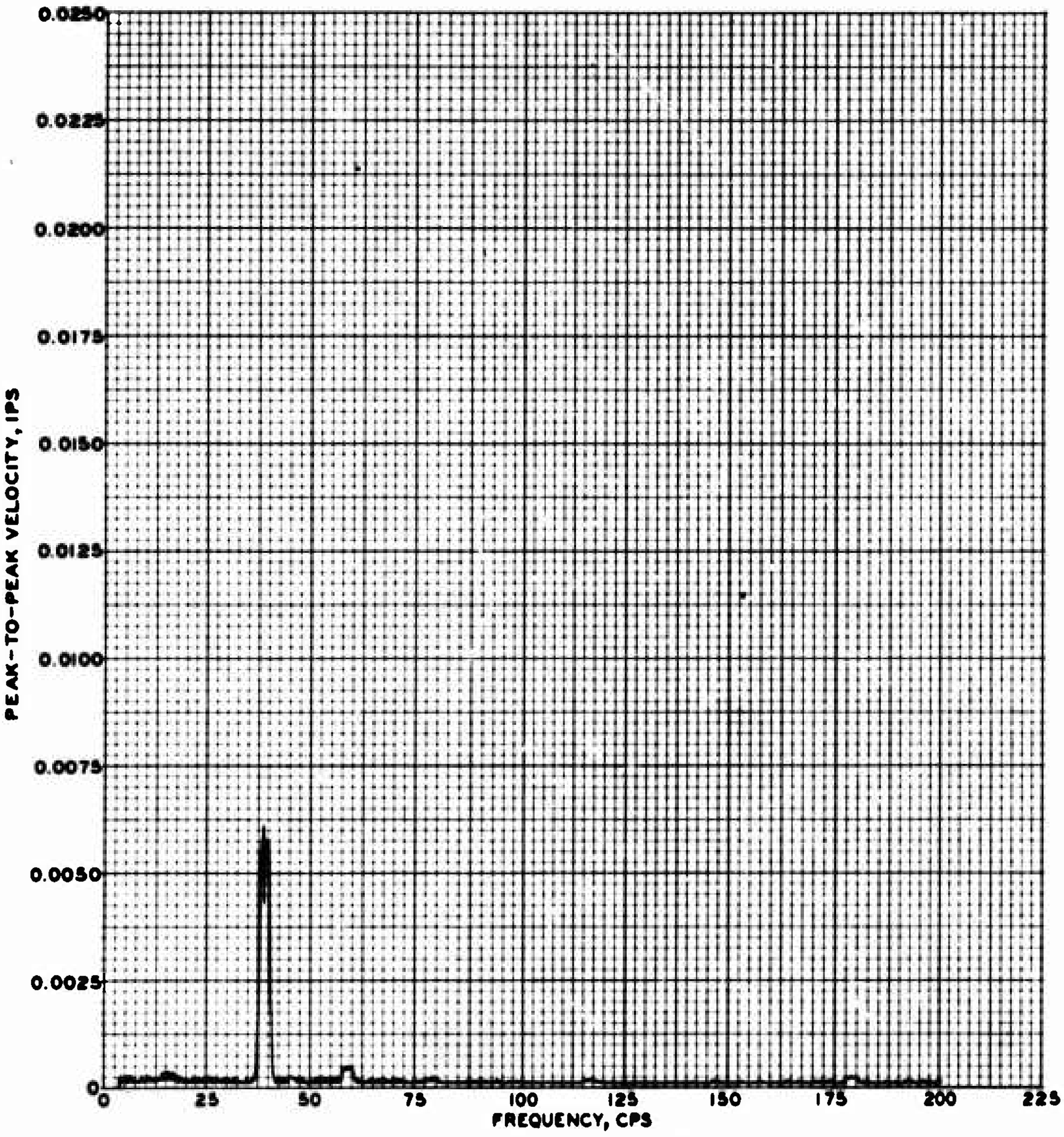
FREQUENCY SPECTRUM ANALYSIS

RUN 58

VERTICAL PICKUP 3 FT FROM VIBRATOR



ACTUAL WAVE SHAPE



SPECTRUM ANALYSIS

VIBRATOR	FREQUENCY CPS	VIBRATOR FORCE LEVEL, LB
ELECTROMAGNETIC	40	100

FREQUENCY SPECTRUM ANALYSIS
RUN 58
VERTICAL PICKUP 13 FT FROM VIBRATOR

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DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Engineer Waterways Experiment Station Vicksburg, Mississippi	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
FREQUENCY SPECTRUM METHOD FOR ANALYZING GROUND-MOTION DATA PRODUCED BY SINGLE AND MULTIPLE VIBRATORY SOURCES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final report

5. AUTHOR(S) (Last name, first name, initial)
Ballard, Robert F., Jr.
Leach, Roy E.

6. REPORT DATE December 1966	7a. TOTAL NO. OF PAGES 72	7b. NO. OF REFS none

8a. CONTRACT OR GRANT NO. b. PROJECT NO. 1L013001A91A c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Miscellaneous Paper No. 4-859 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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13. ABSTRACT Tests were conducted at the Waterways Experiment Station (WES) to investigate controlled single and multiple source vibrations induced in an earth media with the objective of evaluating the benefits of two data reduction techniques in identifying the frequency and amplitude composition of the ground motion at selected locations. Single signals of known frequency and force level were induced to the ground surface by three types of vibrators mounted on a 10-ft-diam concrete base. The resultant particle velocities were measured triaxially at each of four locations: on the base and 15, 35, and 90 ft from the base. After the single source tests, the vibrators were operated simultaneously as a multiple signal source input. Data were again recorded at the same locations. Special tests were then performed with two electrodynamic vibrators on the ground surface operating both singly and simultaneously. Ground motions associated with each type of test were recorded both on oscillograph and magnetic tape recorders. Data were reduced manually and directly compared to an automatic frequency spectrum analysis of the data from the vertically oriented transducers. Results indicate conclusively that highly accurate correlations can be made. Measurements for future ground-motion studies conducted at the WES will be obtained in a manner such that an automatic frequency spectrum analysis can be conducted. The test results also showed that correlations between known input signals from single sources can be directly compared with multiple signals at corresponding frequencies and force levels.

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

Unclassified
Security Classification

14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Ground motion						
Vibration						
Vibrators (mechanical)						

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